MMS OCS Study 2008-005

Biological Characterization/Numerical Wave Model Analysis within Borrow Sites Offshore West Florida Coast
Final Report Volume I
Contract No. 1435-01005-CT-39054

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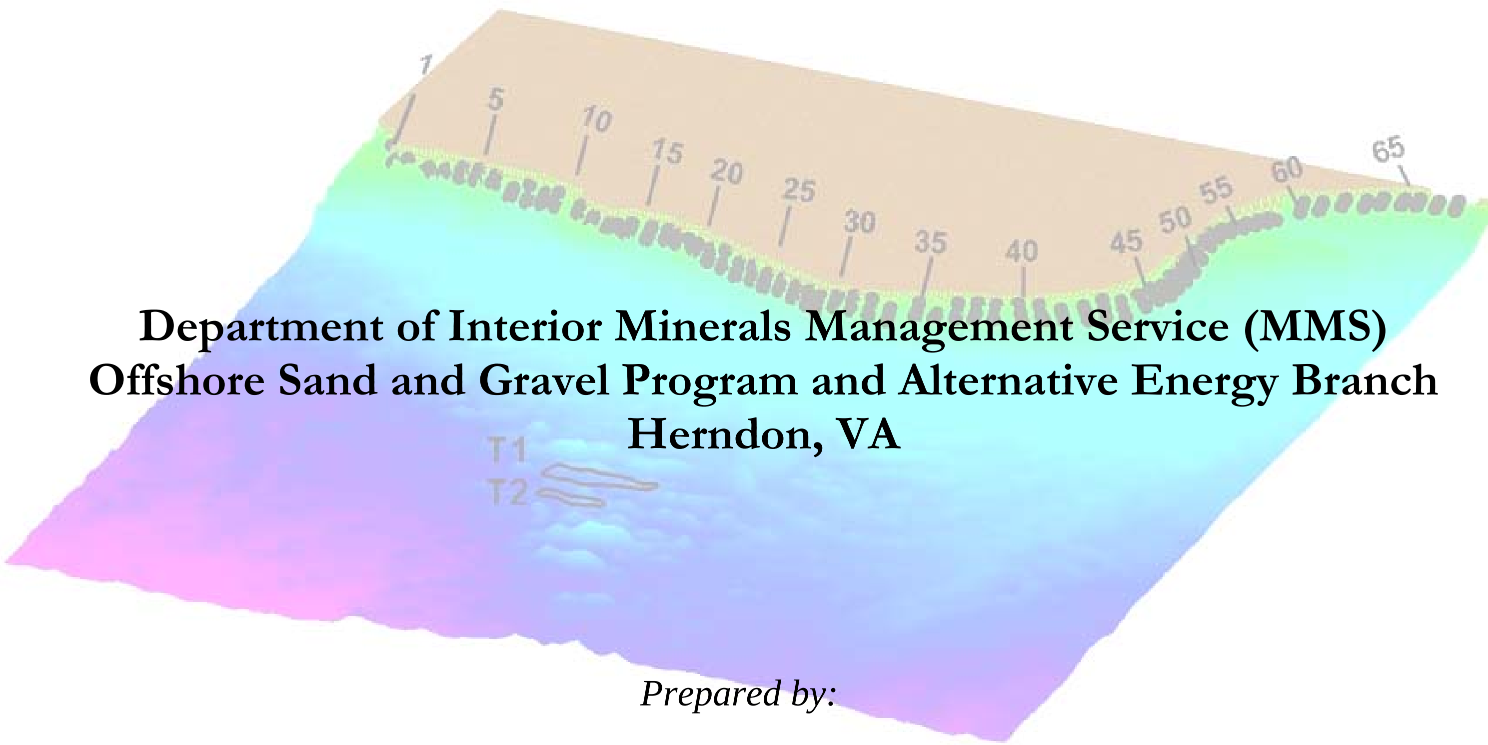

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Offshore Sand and Gravel Program and Alternative Energy Branch
Herndon, VA

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February 2008

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CONVERSION FACTORS

Metric to U.S. Customary

Multiply	by	To Obtain
millimeters (mm)	0.03937	inches (in)
centimeters (cm)	0.3937	inches (in)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	miles (mi)
square meters (m^2)	10.76	square feet (ft^2)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons (gal)
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces (oz)
grams (g)	0.03527	ounces (oz)
kilograms (kg)	2.205	pounds (lb)
metric tons (t)	2205.0	pounds (lb)
metric tons (t)	1.102	short tons
Celsius degrees (ºC)	1.8(ºC)+32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	by	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles	1.609	kilometers
nautical miles	1.852	kilometers
square feet	0.0929	square meters
square miles	2.590	square kilometers
acres	0.4047	hectares
gallons	3.875	liters
cubic feet	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams (g)
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
Fahrenheit degrees	0.5556(ºF – 32)	Celsius degrees

LIST OF ACRONYMS

ADCIRC	Advanced Circulation Model for Oceanic, Coastal, and Estuarine Water
ASTM	American Society of Testing Materials
ATOS	Anti-Turbidity Overflow System
AVHRR	Advanced Very High Resolution Radiometer
BLM	Bureau of Land Management
BMP	Biological Monitoring Program
BOD	Biological Oxygen Demand
BP	Before the Present
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CeTAP	Cetacean and Turtle Assessment Program
CFR	Code of Federal Regulations
CHL	Coastal Hydraulics Laboratory
CIRP	Coastal Inlets Research Program
C-MAN	Coastal-Marine Automated Network
CMS	Coastal Modeling System
COA	Corresponding Onshore Areas
COLREGS	International Collision Regulations
COMPS	Coastal Ocean Monitoring and Prediction System
CO-OPS	Center for Operational Oceanographic Products and Services
CTD	Conductivity Temperature Depth
CZMA	Coastal Zone Management Act
DI	Digestion Index
DO	Dissolved Oxygen
DOI	U.S. Department of the Interior
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ER	Environmental Report
ERDC	U.S. Army Corps of Engineers Research and Development Center
ESA	Endangered Species Act
FDCA	Florida Department of Community Affairs
FDEP	Florida Department of Environmental Protection
FDNR	Florida Deparment of Natural Resources
FFWCC	Florida Fish and Wildlife Conservation Commission
FGS	Florida Geologic Survey
FI	Fullness Index
FMP	Fishery Management Plan
FWC	Florida Wildlife Commission
FWRI	Florida Fish and Wildlife Research Institute
FWS	U.S. Fish and Wildlife Service
GMFMC	Gulf of Mexico Fishery Management Council
GMP	EPA Gulf of Mexico Program

GMT	Greenwich Mean Time
GPS	Global Positioning System
HA	Hectare
HAB	Harmful Algal Bloom
HAPC	Habitat Areas of Particular Concern
ICES	International Council on Exploration of the Seas
INTERMAR	International Activities and Marine Minerals
IOOS	Integrated Ocean Observing System
IRI	Index of Relative Importance
LIDAR	Light Detection and Ranging
MAFLA	Mississippi, Alabama, Florida
MAFMC	Mid-Atlantic Fishery Management Council
MBARI	Monterey Bay Aquarium Research Institute
MBTA	Migratory Bird Treaty Act
MDS	Multi-dimensional Scaling
MHW	Mean High Water
MHWL	Mean High Water Level
MLW	Mean Low Water
MMP	Marine Minerals Program
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MOA	Memorandum of Agreement
MPRSA	Marine Protection, Research, and Sanctuaries Act of 1972
MRFSS	Marine Recreational Fishery Statistics Survey
MSA	Magnuson-Stevens Fishery Conservation and Management Act
NEPA	National Environmental Policy Act
NESDIS	National Environmental Satellite and Data Service
NGDC	National Geophysical Data Center
NGVD	National Geodetic Vertical Datum
NHPA	National Historic Preservation Act
NL	Notocord Length
NMFS	National Marine Fisheries Service
NOAA	National Oceanic & Atmospheric Administration
NOS	National Ocean Survey
NPS	National Park Service
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OIP	FDEP Office of Intergovernmental Programs
ONR	Office of Naval Research
OSP	Optimum Sustainable Population
POM	Princeton Ocean Model
ROSS	Reconnaissance Offshore Sand Search
SAFMC	South Atlantic Fishery Management Council
SCUBA	Self-Contained Underwater Apparatus
SCUFA	Self-Contained Underwater Fluorescence Apparatus
SEACOOS	Southeast U.S. Atlantic Coastal Ocean Observing System
SL	Standard Length

SMS	Surface Water Modeling System
TSHD	Trailer Suction Hopper Dredge
USACE	U.S. Army Corps of Engineers
USACOE	U.S. Army Corps of Engineers
U.S.C.	U.S. Code Citation
US C&GS	U.S. Coast and Geodetic Survey
USCG	U.S. Coast Guard
USCS	Unified Soils Classification System
USDOI	U.S. Department of the Interior
USF	University of South Florida
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIMS	Virginia Institute of Marine Science
WABED	Wave-Action Balance Equation with Diffraction
WANT	Western North Atlantic Tidal
WES	Waterways Experiment Station
WIS	Wave Information System

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(Provided as Volume II)

1.0 INTRODUCTION

This technical report is a product of literature research and field studies conducted from 2005 to 2007 in fulfillment of the U.S. Department of the Interior (USDOI), Minerals Management Service (MMS) Contract No. 1435-01-05-CT-39054 *Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the West Coast of Florida/Physical Implications of Sand Dredging on the Topography of the West Florida Shelf.* In this study, physical and biological data were analyzed for decision-makers that regulate marine minerals and for those that are interested in using beach compatible material from the Federal Outer Continental Shelf (OCS). The MMS Marine Minerals Program (MMP) provides policy direction and administers lease agreements for the development of marine mineral resources on the OCS. Results of analyses from this study identified recommendations for mitigating potential dredging impacts to protected species, biological communities and their habitat off the southwest coast of Florida. Suggestions for additional studies that can promote understanding and prevent potential dredging impacts are included in the conclusions section. These suggested studies will assist future OCS lessee applicants in extracting marine mineral resources in an environmentally safe and economically efficient manner.

This study concentrates on Florida's southwest coast and is one of several similar ongoing OCS studies directed by the MMP in cooperation with 14 partner states along the Atlantic Coast and in the Gulf of Mexico. Collectively, these studies serve to document and analyze geological and environmental information on OCS sand deposits that may be suitable for beach renourishment and wetlands protection projects. MMS established a Federal/State partnership in July 1994 with the State of Florida to identify offshore sand resources suitable for beach nourishment (MMS, 1999). Studies of OCS resources offshore of east central and northeast Florida were initiated because of the increased demand for beach quality sand has risen in different regions of the state. In a Florida Department of Environmental Protection (FDEP) report on Critically Eroded Beaches (FDEP, 2006), there were 332.4 miles of critically and non-critically eroded beaches statewide in 1989. In 2006, the number of statewide beach miles categorized as critically and non-critically eroded increased by about one-third. Within the study area (Sarasota, Charlotte, Lee, and Collier counties) 63% of the total beach miles considered critical and non-critical represent 15% of the statewide total.

Much of the increased beach erosion is attributed to tropical depressions, tropical storms, and hurricanes that impacted Florida from 1994 to 2005. Other factors such as human-induced alterations of inlets and inlet management, and armoring in coastal areas have contributed to the need for ongoing beach fill maintenance. Another factor driving the search for beach compatible material is population growth in coastal counties. In 2005, 16 million people resided in Florida, 80% lived in 35 coastal counties and by 2025 Florida's total population estimate is expected to reach 25 million (FDCA, 2006).

The MMS under the Outer Continental Shelf Lands Act (OCSLA) (43 U.S.C. 1331, et. seq.) is authorized to convey rights to OCS sand, gravel, or shell resources for shore protection, beach, or wetland restoration projects, or construction projects funded in whole or part by or authorized by the Federal Government. The vehicle for conveyance is normally a negotiated lease agreement between MMS and the lessee. The negotiated leases are based on the results from site-specific environmental studies. Information on the specific process of noncompetitive and completive leases can be found in OCS MMS Report 2006-042 (OCS MMS, 2006). Exploration and development of mineral resources on submerged Federal OCS lands is governed by several laws and policies including: the OCSLA, the National Environmental Policy Act

(NEPA), the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), the National Historic Preservation Act, the Clean Water Act (NHPA), the Magnuson-Stevens Fishery Conservation and the Management Act (Sustainable Fisheries Act), and Code of Federal Regulations [CFR] Title 30: Mineral Resources including Parts 280, 281, and 282. For the last decade, MMS administered and funded a number of environmental site-specific studies to obtain information for managing the activities of marine mineral extraction in an environmentally safe manner. In 2007, the MMS notified states that limited funding and budget shortfalls would prevent MMS from conducting future site-specific studies. Consequently, it will now be the responsibility of the sand recipient (e.g., state or local community) to provide all necessary information, including, but not limited to, site-specific environmental studies. Additionally, the OCS sand lessee will fund analysis of the proposed activity, as required under the NEPA. The MMS asked states to identify and prioritize coastal protection projects to allow the Sand and Gravel Program to allocate its reduced resources more effectively and efficiently. From now on, the MMS will assist future lessee applicants on a case-by-case basis with advice on the type of environmental analysis required under NEPA and critical review of the NEPA related analyses and documents submitted by the applicants or applicants' consultants. The purpose of the review will be to determine the possible environmental impact, if any, of the proposed project and determine possible mitigation efforts.

1.1 Study Objectives

The primary goal of the study as directed by MMS is to characterize the physical and biological environments of west central Florida offshore sand sources as well as identify and address potential environmental impacts that may result from dredging specific sand borrow sites. Research and field study information was collected and analyzed to assist in developing criteria for future negotiated agreements, NEPA documents (Environmental Assessments [EAs] and Environmental Impact Statements [EISs]), and other requirements for use of Federal sand and gravel deposits from the study areas.

Identification of Physical Characteristics

The objectives set forth by MMS for physical and biological characterization of sand source sites and potential onshore impacts were as follows:

- Examine the potential alteration in the local wave field following dredging and the sand excavation from within potential sand borrow sites located offshore of Florida’s west coast.

- Examine the potential for increased wave action after dredging within potential sand borrow sites. Also, examine any resultant adverse localized changes in erosional patterns and longshore coastal transport, which could result in significant losses of beach sand after renourishment.

- Examine the potential for changes in local sediment transport rates because of altering the local bathymetry, particularly in light of the recent studies that indicate bathymetry influences the manner in which waves approach the shoreline during storm events.

- Examine the cumulative physical effects of multiple dredging events as well as extractions of large volumes of material within the identified borrow sites.

- Using numerical wave modeling, generically examine potential adverse effects on the physical wave field resulting from dredging along the west Florida shelf, while taking into account the differences in topography between this and the Atlantic offshore area.

Identification of Biological Characteristics

- Characterize and evaluate benthic habitats, biological communities (infauna, epifauna, demersal, and pelagic fishes), and sediment grain size in potential borrow areas. Biological field data collected during the study will be used in conjunction with existing literature provide maximum habitat and community characterization.

- Assess the potential effects of offshore sand dredging on benthic and pelagic communities, including an analysis of the potential rate and success of re-colonization following cessation of dredging.

- Using the procedures and conclusions set out in the *National Academy of Sciences (NAS) Special Report 262: A Process for Setting, Managing, and Monitoring Environmental Windows for Dredging Projects*, develop a time schedule of environmental windows that best protects benthic and pelagic species from adverse environmental effects.

- Project Scheduling Considerations: Evaluate times for dredging in the sand resource areas relative to transitory pelagic species.

1.2 Study Area Description

The project study area begins 9 to 10 nautical miles in Federal waters off the west coast of Florida along Sarasota, Charlotte, Lee, and Collier Counties. Three sand ridges were chosen for the study. Two sand ridges, Toms' Hills (T1 and T2 shoal system) are located close to each other and are approximately 13 miles west of Sanibel Island (see Figure 1-1). T1 is oriented northwest southeast and is approximately 2.2 square miles in area. The T2 sand ridge is approximately 1 square mile in area. T1 and T2 ridges lie in approximately 46 feet of water depth (about 14m). The highest points or crests of the ridges rise to about 32 to 36 feet (10-11m) above the surrounding depth. The third sand ridge, Siesta Shoal, is located about 13 miles west of Siesta Key, Sarasota County. This sand ridge covers approximately 1 square mile in area rising about 5 feet above the surrounding bottom depth of 50 feet (15 m).

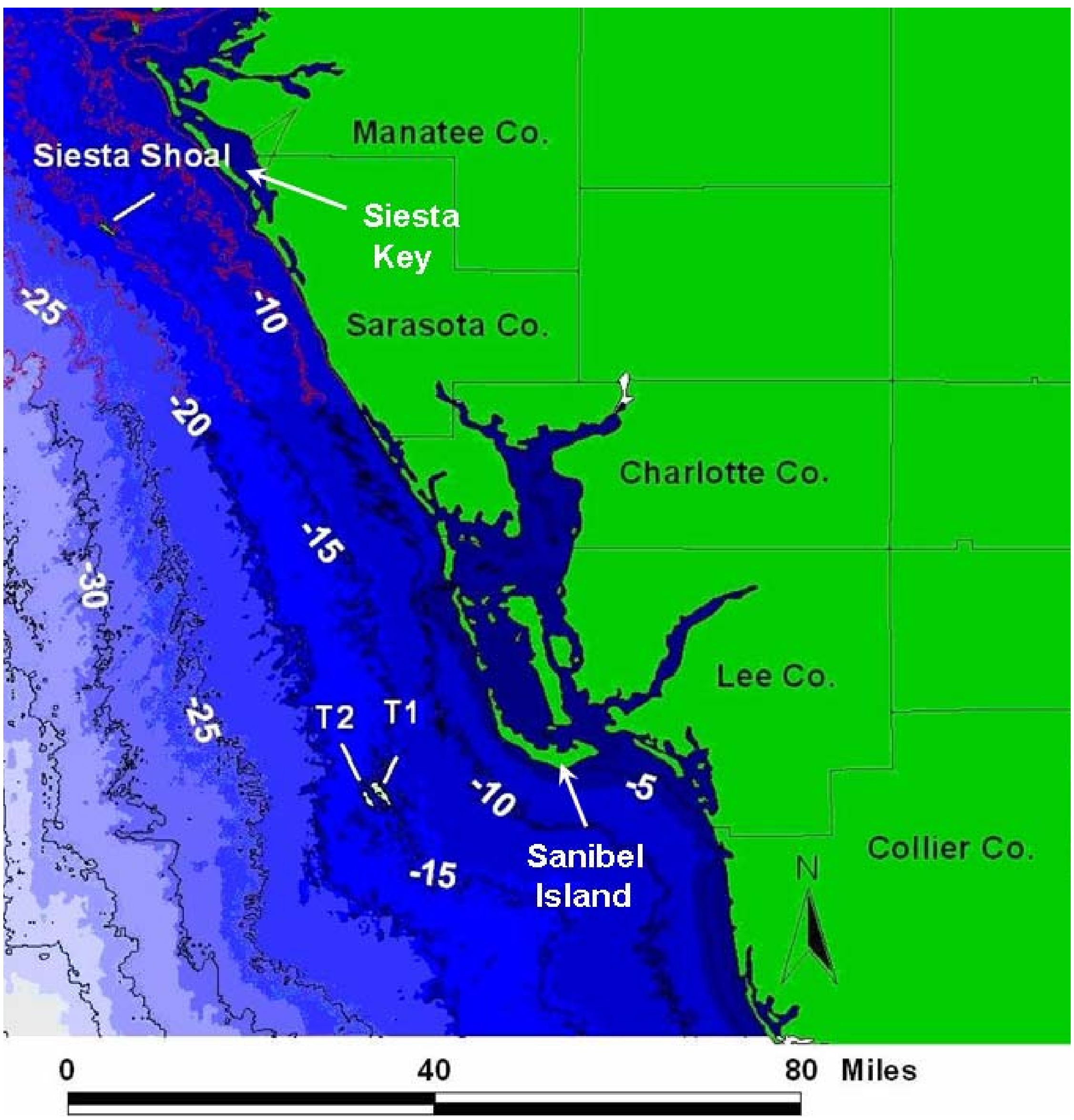


Figure 1-1. Location of the Siesta Shoal, T1, and T2 sand ridge sites for biological and physical characterization. Depth contour interval is 5m (16.5 ft).

2.0 EXISTING PHYSICAL AND BIOLOGICAL INFORMATION

2.1 Overview of Historical and Modern Physical Environment

The selected shoals of this project located on the inner continental shelf off the west Florida coast are depicted in Figure 1-1. The regional shelf bottom topography and the MMS study area boundaries are shown in Figure 2-1. The west Florida shelf is among the widest in the world extending more than 300 miles in width from the modern shoreline to the break in slope at approximately 200 meters depth. Inner shelf topography to depths of approximately 60 feet (about 20 meters) has been mapped in detail. These survey data, which extend back more than 100 years, are readily available from the National Geodetic Data Center's Coastal Relief Model. Publicly held data from the Continental Slope and Rise, as well as the deep Gulf of Mexico Basin, are also available from the National Geodetic Data Center's marine geology mapping program. The U.S. Geological Survey (USGS) and associated academic partners at the University of South Florida (USF) have provided major contributions to the geologic knowledge of the inner continental shelf stratigraphy and sedimentology through recent studies. The USGS has been active in compiling shoreline change data for the west Florida coast and other areas of the Gulf Coast of the U.S. The Florida Department of Environmental Protection (FDEP) has likewise contributed to the body of knowledge of Florida's coast and the inner continental shelf within state waters by compiling information related to Joint Coastal Permits submitted by counties and their geotechnical and engineering consultants. FDEP sponsors ongoing coastal research and statewide monitoring programs that are carried out by staff and through partnerships with universities and consultants. The FDEP initiated the Reconnaissance Offshore Sand Search (ROSS) database, which is designed to compile geologic and geophysical data of nearshore, sand search projects into an interactive database. The database is complete for the Panhandle region of Florida and has been partially extended into west central, southwest Florida, and east Florida. Many of the data sets discussed in the report are represented in ROSS, which can be accessed at URL http://ross.urs-tally.com/.

The physical oceanography of the west Florida continental shelf has been the subject of academic research by various Florida universities for several decades. Within the past five years, data collection and modeling efforts under the congressionally funded Southeast U.S. Atlantic Coastal Ocean Observing System (SEACOOS) have added the capability of viewing oceanographic processes of the Florida shelf in real time and viewing some types of forecast up to two days in advance. Results of previous studies and examples of real time data are presented in the section dedicated to Physical Oceanography.

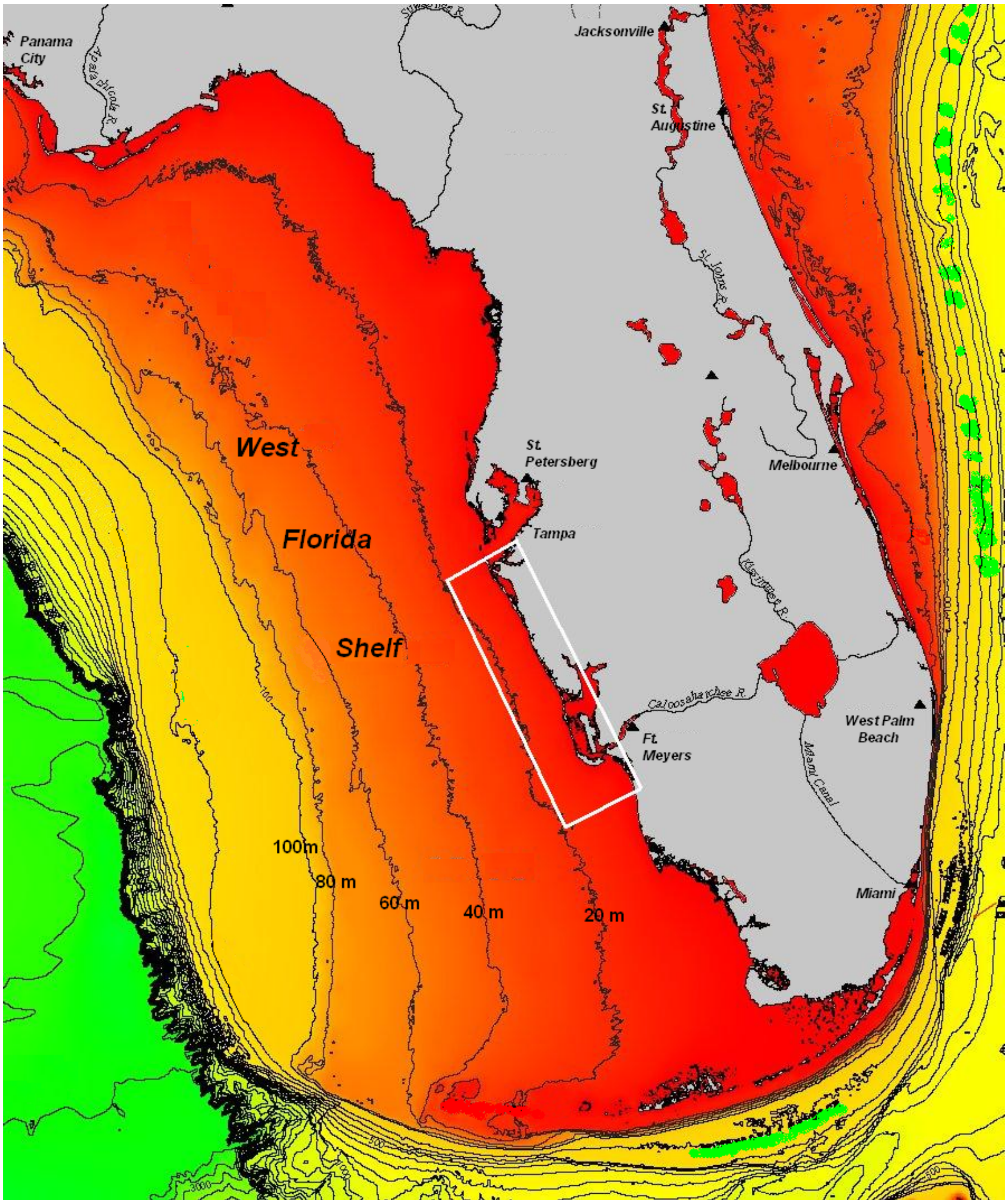


Figure 2-1. Study area and regional shelf topography is shown in intervals of 20 m (from the National Geophysical Data Center). The MMS study area is located in the white rectangle.

2.2 Geologic History of Florida's West Coast

Data analysis and previous work describing the recent geologic history of west Florida as it relates to this project can be found in several key publications of the Florida Geologic Survey (FGS). A primary resource is a book entitled "The Geomorphology of the Florida Peninsula" by White (1970) which provides an overview of the geologic history and geomorphic framework for the physiographic provinces of the Florida Peninsula. A more recent publication by Lane (1994) provides an overview of Florida's geologic history and geologic resources. These works emphasize the close link between cycles of sedimentation in response to sea level fluctuation over the past 65 million years throughout the Cenozoic Era. As described by the Florida Geologic Survey, Florida's Cenozoic sediments, which contributed to the formation of the modern coastal and inner shelf settings, include two major groups: the Paleogene and Neogene sediments of the Quaternary Geologic Period. Paleogene sediments are fossiliferous carbonate sediments that include very little siliciclastic sediment (terrigenous quartz sands, silts and clays). The lack of silica-rich sediments from this period is due to the existence of a large "Gulf Trough" separating the Florida Platform from the siliciclastic source of the Appalachian Mountains.

In the late Paleogene, the Appalachians were uplifted, erosion rates increased, and siliciclastic sediments filled the Gulf Trough. Siliciclastic sediments then encroached upon the carbonate depositional environments. The sediments deposited during the Neogene were primarily quartz sands, silts and clays with varying amounts of limestone, dolomite and shell. In southern Florida, carbonate sediments remained predominant because most of the siliciclastic sediments, moving south with the coastal currents, were funneled offshore. The area of the modern-day Everglades was a shallow marine bank where calcareous sediments and bryozoan reefs accumulated. These sediments compacted and eventually formed the limestone that underlies the Everglades today. Details and further references describing the Paleogene and Neogene evolution of Florida can be found on the FGS web site at http://www.dep.state.fl.us/geology/.

The project area lies within the Southern Distal Physiographic Zone of the Florida Peninsula. Here the geologic terrain is constructed from a series of low-lying carbonate platforms that were formed in the Pleistocene Epoch. The lithology of these formations is almost completely calcareous, consisting of oolites, coral rock and reef detritus, and cemented shell material. The oldest and lowermost of the formations, the Anastasia Formation, can include small amounts of terrigenous quartz in sand size fractions. Consistency of these units primarily ranges from unconsolidated to weakly lithified, and in some areas to well-lithified limestone.

The carbonate formations were produced by deposition in shallow marine waters at multiple high stands of sea level in combination with periods of erosion, dissolution, and karstification during lower stands of sea level. This process has continued from Pamlico Time of the mid-Pleistocene Epoch, through the Late Pleistocene Silver Bluff Time, until the recent or Holocene Epoch of the present day. In Pamlico Time, about 120,000 years before present, relative sea level stood about 25 feet above modern sea level and the Southern Distal Zone was a shallow, submerged, carbonate bank similar to the Modern Bahama Banks. Unlike the distinctive terraces marking the shoreline systems of central, east, and southeast Florida, the interior lowlands along the west coast of Florida have been topographically subdued or absent relict shoreline deposits. The process of sea-level fluctuation in South Florida has resulted in a series of carbonate banks, not specifically related to distinctive shoreline positions in the Pleistocene Epoch. These carbonate surfaces remain largely unchanged in topography since their origin, and the intersection of modern sea level with these relict carbonate banks largely determined the shoreline position in South Florida.

The project area from Sarasota to Sanibel Island is part of the Gulf Barrier Chain and Lagoon section of Florida's west coast. Barrier islands are generally only fully developed between Anclote Key on the north and Marco Island to the south. Unlike the barrier islands of Florida's east coast, the Gulf Barrier/lagoon system of the west coast seems to derive a local sand supply by erosion of headlands (White, 1970). Thus, barriers first develop as spits extending from eroding sandy headlands formed by divides between topographically low areas that shape the modern estuaries. The source of quartz siliciclastic sands from which the modern Gulf Coast Barriers are formed is likely eroded quartz-rich Neogene sands deposited in shallow marine waters off the proto-Florida Peninsula about 23 million years ago. Since that time, the fine sands may have been recycled through beach and nearshore deposits related to numerous high stands of sea level before being included in the modern barrier complex.

Coastal morphology to the north and south of the Gulf Coast Barrier Chain is the product of submergence of a gently sloping "sand-starved" limestone platform. In these areas, the offshore depths may not reach 20 to 30 feet (66 - 98m) until 4 to 6 miles offshore. In contrast, the barrier chain morphology is considered to be the product of progradation across the limestone platform resulting in a relatively steep wave-built shoreface slope compared to the gradient of the underlying limestone surface. Thus, in the Siesta Key and Sanibel Island areas, similar to other locations within the prograding barrier chain, offshore slopes are constructional reaching depths of 18 to 20 feet within approximately 2.5 miles of shoreline. Therefore, the beach quality quartz-rich sands will be confined to this nearshore zone unless relict shoal features generated in nearshore waters can be found at greater depths. Figure 2-2 from White (1970) shows the relationship between the prograding barrier island chain and submerged limestone platform sections of the Florida west Coast. The inner shelf topographic gradient is somewhat larger in the barrier island section compared to gentler inner shelf gradients of the sand starved limestone sections to the north and south.

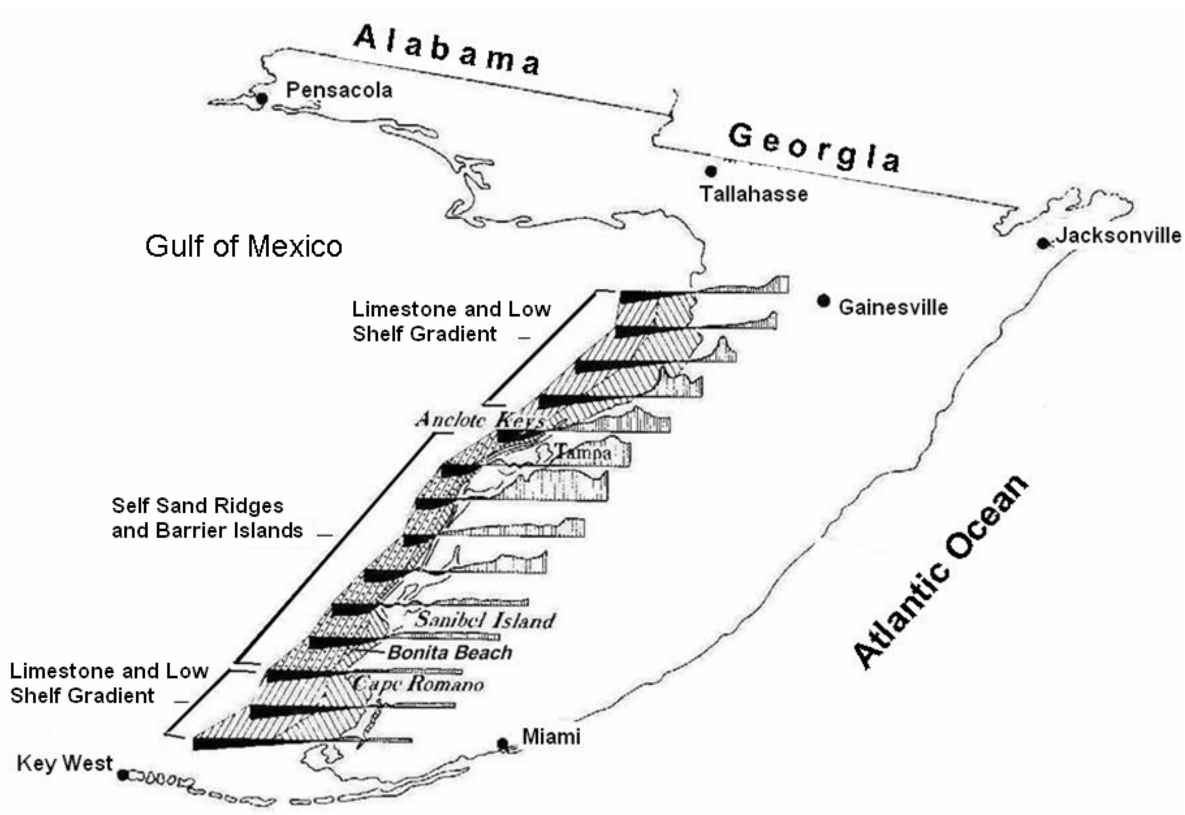


Figure 2-2. Arrangement of the sandy barrier chain vs. limestone dominated sections of Florida's west coast (from White, 1970).

2.3 Geology of the Continental Shelf

The west Florida continental shelf has received considerable attention from the marine geology community. The potential for sand and gravel resources along with the potential for oil and gas production from reservoir sediments off the deep continental margin of the Florida coast have been the primary reasons for interest in the geology of this region. Furthermore, the co-location of a USGS marine geology branch office with the Marine Science Program at the University of South Florida has generated academic interest in understanding the origin and evolution of the west Florida continental shelf.

Earlier studies of the west Florida shelf area indicated that the pre-Holocene carbonate surface described in Section 2.2 is covered by thin, patchy deposits of quartz sand and carbonate gravel (Gould and Stewart, 1955; Cherry et al., 1970; Ginsburg and James, 1974; Riggs and O'Conner, 1974; Doyle and Sparks, 1980). These studies also described extensive hardbottom exposures present between the zones of unconsolidated sand and gravels. Prior to the most recent regional investigations conducted jointly by the USGS and the USF, considerable effort was focused on understanding the stratigraphy and morphodynamics of the barrier-island system (Davis, 1989; Davis and Hine, 1989; Davis et al., 1992; Davis, 1994). The modern coast is characterized by a barrier-island/lagoon system complex having morphologic features attributed to both tide- and wave-dominated processes. These studies published in the 1980s and 1990s recognized that the inner shelf contained a variety of sedimentary features including sediment-starved sand-ridge systems displaying a wide variation in morphology and orientation (Gelfenbaum and Guy, 1999). These studies also noted that the Tampa Bay ebb shoal was ranked as the largest in the Gulf of Mexico (Hine et al., 1986). Other investigations suggested the importance of antecedent topographic control on coastal evolution, and the importance of nearshore sediment supply on barrier-island evolution (Evans et al., 1985; Davis and Kuhn, 1985; Hine et al., 1987; Davis et al., 1992).

Beginning in the mid-1990s, the USGS and the USF jointly conducted studies to describe in more detail, but on a regional basis, the Holocene sequence onlapping the west-central Florida shelf. The goal of these studies was to define the geologic framework and depositional history of nearshore sediments and to establish their relationship with the modern barrier island system of west Florida. A key paper by Locker et al. (2003) provides an overview of the study conclusions. Companion papers by Brooks et al. (2003) and Davis et al. (2003) provide more detail on the facies architecture of the continental shelf and the barrier-island stratigraphy, respectively. Papers by Twichell et al. (2003) and Harrison et al. (2003) describe local high resolution data sets designed as case studies of individual and groups of sand bodies according to sub-regions of the west Florida shelf. In 2003, these and other related publications were compiled in a Special Issue of *Marine Geology*, Volume 200. The details of the USGS-USF project methods and results, can be found in a series of USGS Open File Reports (Locker et al., 2000, Locker et al., 2001a,b; Locker et al., 2002a,b,c,d,e,f,g,h). An overview of the data sets from these reports can be found in Locker et al. (2003). Figure 2-3 shows the survey lines and locations of core borings acquired during the USGS sponsored regional studies of the west Florida shelf.

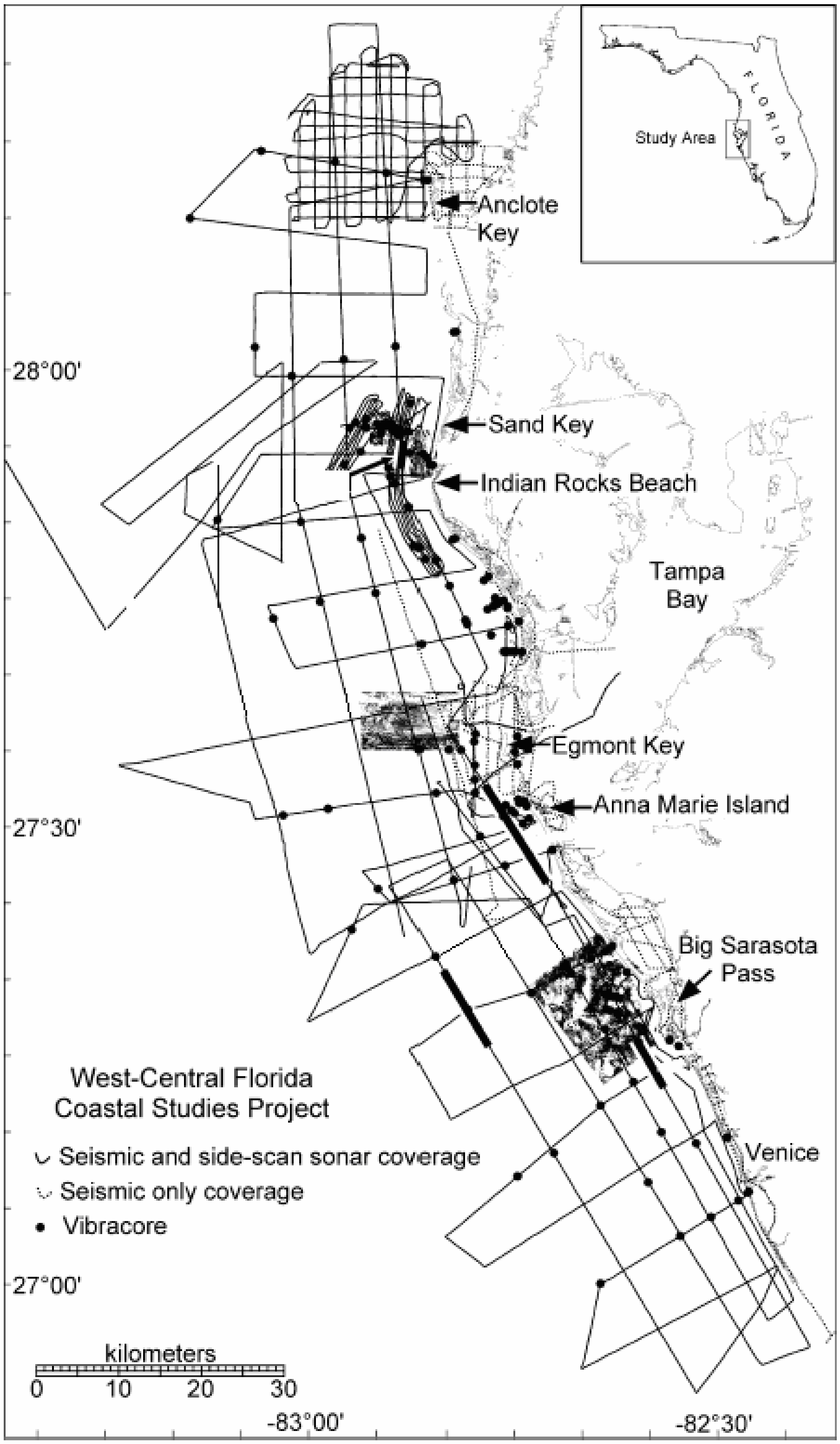


Figure 2-3. Survey lines and core locations from the USGS regional study of the west Florida coastal area and inner continental shelf (from Locker et al., 2003).

Papers by Brooks et al. (2003), Duncan et al. (2003), and Ferguson and Davis (2003) described the geologic history of the west Florida inner shelf during the mid to late Cenozoic Miocene to Pleistocene Epochs. The development of the modern barrier system and shelf sand ridges are interpreted in view of the antecedent topography remaining from the early stages of geologic development as well as with respect to the available sediment supply.

2.3.1 Pre-Holocene Geology

The major features described from a series of cross-sections assembled from the field data include a thin and discontinuous Holocene sequence that unconformably overlies a deformed Cenozoic section containing solution collapse structures, and a relatively flat erosion surface that truncates the pre-Holocene strata (Locker et al., 2003). The regional pre-Holocene stratigraphy is important because of the influence of antecedent topography and relict sediment sources on the development of Holocene depositional environments. Figure 2-4 provides an example of one of the major stratigraphic features of the west Florida shelf. Wavy parallel and chaotic seismic back scatter sections characterize the regional bedrock section of the valley fill sequence identified as the Arcadia Formation of the Miocene age (Duncan et al., 2003). These seismic patterns are characteristic of vertical deformation and lithostratigraphic inhomogeneities caused by karst processes. The bedrock deformation and associated subsidence forms km-scale shelf-valley depressions (Figure 2-4). From Tampa Bay south, such shelf valleys are well developed. In contrast, shelf valleys are absent north of John's Pass at approximately 27^{o}47'PN. The origin of the shelf-valley systems is thought to be a collapsed deformation due to dissolution of the mid-Cenozoic platform carbonates. The relief of these depressions is of the order of several tens of meters. In some local areas, erosion truncation plays a role in valley formation. The shelf-valley fills are assumed late Miocene to Pliocene in age (Duncan et al., 2003; Ferguson and Davis, 2003). No evidence has been found for deformation of Holocene strata by karst processes (Locker et al., 2003).

An erosional unconformity marks the base of the Holocene section. This unconformity reflects extensive periods of exposure and erosion processes driven by numerous Quaternary sea-level fluctuations. During the Holocene transgression, evidence for a ravinement on this surface is inconsistent since not all areas were subject to shoreface erosion (Brooks et al., 2003). Pre-Holocene bedrock is exposed as hardbottom throughout the study area (Harrison et al., 2003).

Some exposures include meter-scale ledges that support benthic communities and bio-eroders that constitute an important modern sediment source (Obrochta et al., 2003). Core borings from inner shelf areas commonly recovered pre-Holocene weathered limestone and residual clay-rich sediments (Brooks et al., 2003). Beneath the barrier-island system, Miocene limestone, residual clay facies, and Pleistocene sand are commonly present below the Holocene onlap (Locker et al., 2003 Davis et al., 2003).

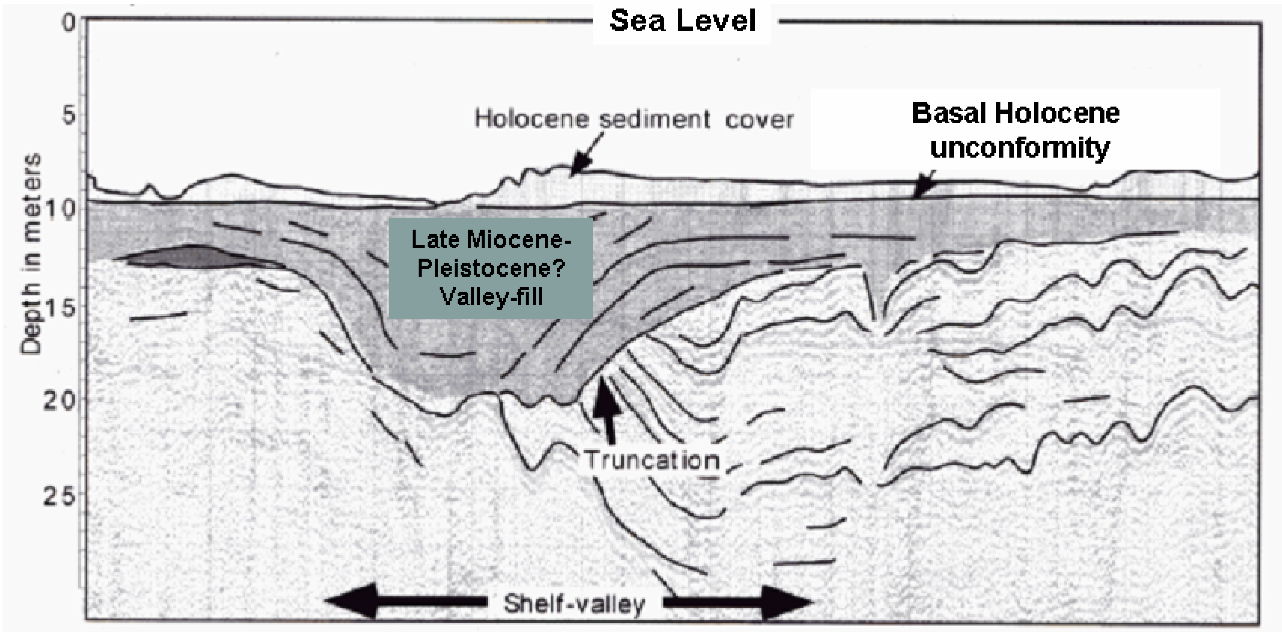


Figure 2-4. An interpretation of shelf valley fill sequence from a sub-bottom seismic cross-section. The seismic signature of the overlying thin Holocene sediments is nearly indistinguishable from the Miocene to Pleistocene sections below (from Locker et al., 2003).

2.3.2 Holocene Geology of the West Florida Shelf

Results from the USGS and other studies show that the inner continental shelf can be divided into three main areas based on a combination of bedrock geology, associations of sedimentary types and patterns of sediment thickness. The area north of Tampa Bay is characterized by shallow depths across the inner continental shelf and NW-SE trending sand ridges. Here the 10 m isobath is located 10 to 16 km seaward of the shoreline. A central region includes the sand resources of the Tampa Bay ebb shoal. A deeper shelf characterizes the southern area where the 10 m isobath is located only 3 to 8 km seaward of the shoreline. This area includes a sand-ridge system of variable trend.

Acoustic backscatter in the sub-bottom records of the Holocene section collected by the USGS was nearly absent. However, weak reflections associated with the ravinement surface at the top of the pre-Holocene were observed at some locations (see Edwards et al., 2003), and occasional low-angle reflections within the Tampa Bay ebb-tidal delta indicate late Holocene progradation of this depositional feature.

Sand-ridge distribution controls the surficial morphology of the inner continental shelf of the west-central Florida shelf in all areas away from the Tampa Bay ebb shoal. Figure 2-5 shows a sand ridge and large sand wave orientations interpreted from bathymetric data assembled by Gelfenbaum and Guy (1999). Sand-ridge lineations are approximately 1 km wide and spaced several km apart. There is a trend of increased spacing of the ridges with depth. However, ridge morphology at depths greater than 12 m has not been mapped in detail.

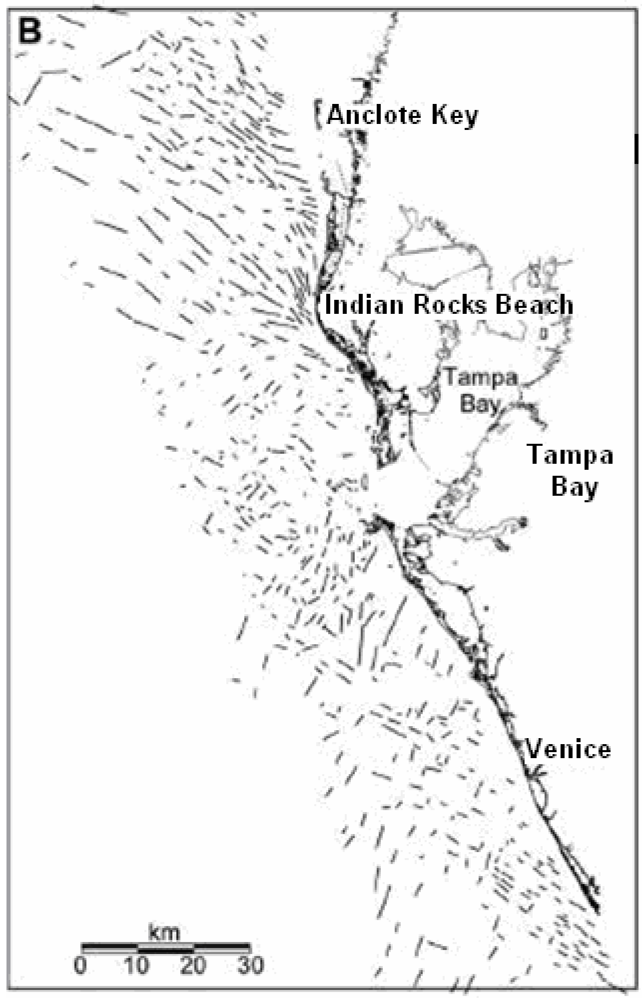


Figure 2-5. Interpretation of sand-ridge and large sand-dune orientations (from Locker et al. 2003). Regional trends of sand ridge orientation indicate both onshore shore and north-south variation.

North of Tampa Bay

North of Tampa Bay sand-ridges trend NW-SE at oblique angles of 30 to 65 degrees to the shoreline. The sand-ridge orientations are more variable around the Indian Rocks Beach headland well north of Tampa Bay. Seaward of 10 m water depth, the ridge trends are more consistently oriented at approximately 50 degrees with respect to the modern shoreline forming an oblique angle opening to the north. At the entrance of Tampa Bay, ridges are not clearly developed and the Tampa Bay ebb shoal morphology controls the local topography (Donahue et al., 2003). The sand-ridge systems south of Tampa Bay are oriented at oblique angles to the shoreline and include mixed NW-SE and NE-SW trends. NE-SW trends at 45 to 55 degrees relative to the shoreline are common in the nearshore out to 10 m water depth. In 10 to 15 m water depths, mixed NW-SE and NE-SW trends at 30 - 50 degree angles to the coastline are inferred from bathymetry. In greater than 15 m water depth, NE-SW trends of 50 to 60 degrees are common.

The transgressive surface on which Holocene sediments were deposited is relatively flat allowing the bathymetric surface to be an indication of sediment thickness. Therefore, most sediment accumulation, patterns correspond to the low-relief sand-ridge morphologies (0.5 – 2 m of relief). Holocene sediment accumulations reaching 3 to 4 m are associated with small ebb-shoals in the nearshore (S.E.A., 2002) or localized sand-ridge crests offshore. Figure 2-6 illustrates a seismic section and the associated reflector interpretation for a sand ridge in Federal waters, just south of Tampa Bay entrance and seaward of Siesta Key. This particular ridge, Siesta Shoal, is one of the study areas selected for analysis in the current MMS project.

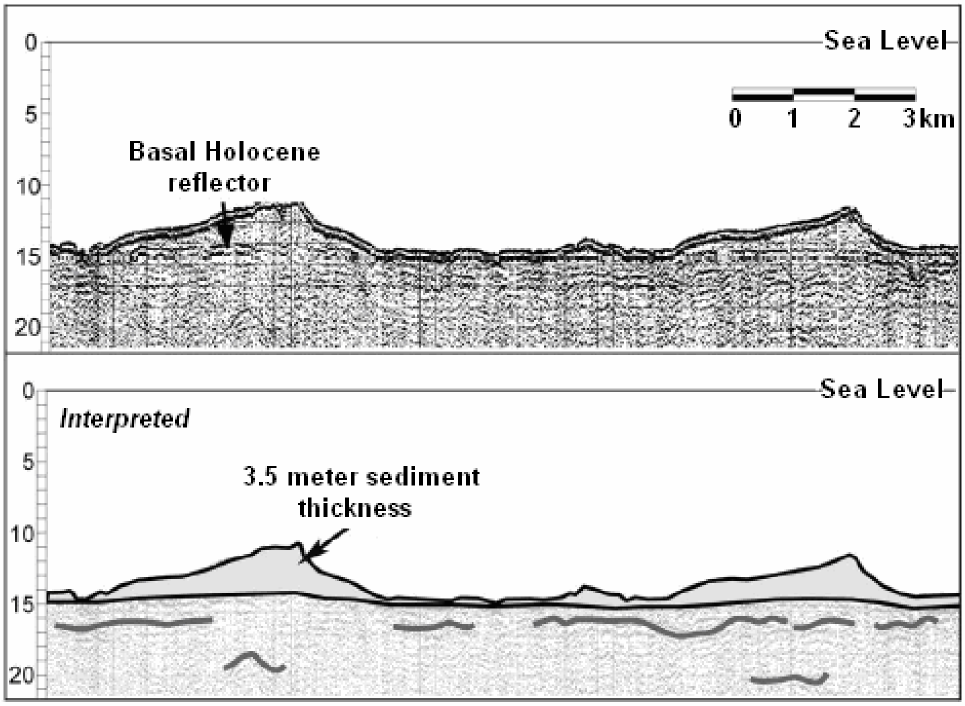


Figure 2-6. Seismic cross-section through the Siesta Shoal selected for analysis in the current MMS project. The shoal is situated 14 miles offshore of Siesta Key in water depths of approximately 30-40 feet (from Locker et al., 2003).

The Tampa Bay Vicinity

The Tampa Bay ebb shoal is formed by a thicker Holocene sequence beneath the barrier islands in this region. The ebb-shoal extends approximately 10 km offshore and combined with smaller nearby inlets has resulted in late-Holocene sediment accumulation of 5 m or greater in a nearshore zone 20 to 25 km wide centered on the mouth of Tampa Bay. These deposits are largely confined to state waters. There is limited sediment cover offshore between 10 and 15 m of water depth, and then in 15 to 20 m water depths there are numerous local sand accumulations of 4 m or more.

North of Tampa Bay and offshore of Indian Rocks Beach, Holocene sediment thickness, as in other areas, is determined by sand-ridge trends and the occurrence of large sand waves (100-m-scale bedforms) that form the sand ridges in this area. Figure 2-7 shows a seismic cross-section and the associated interpretation from this area (Harrison et al., 2003; Locker et al., 2003). Sediment thickness over 2 m in this area is infrequent; more than 50% of the sea floor in 10m water depth was interpreted as hardbottom or a coarse sediment veneer. However, local accumulations of 4 m or greater in sediment thickness were found 20 to 25 km offshore (Locker et al., 2003). Figure 2-8 shows an example of an individual sand ridge well offshore of Indian Rocks Beach that is currently being investigated for acoustic properties by the University of South Florida in a study sponsored by the Office of Naval Research (Howd et al., 2003).

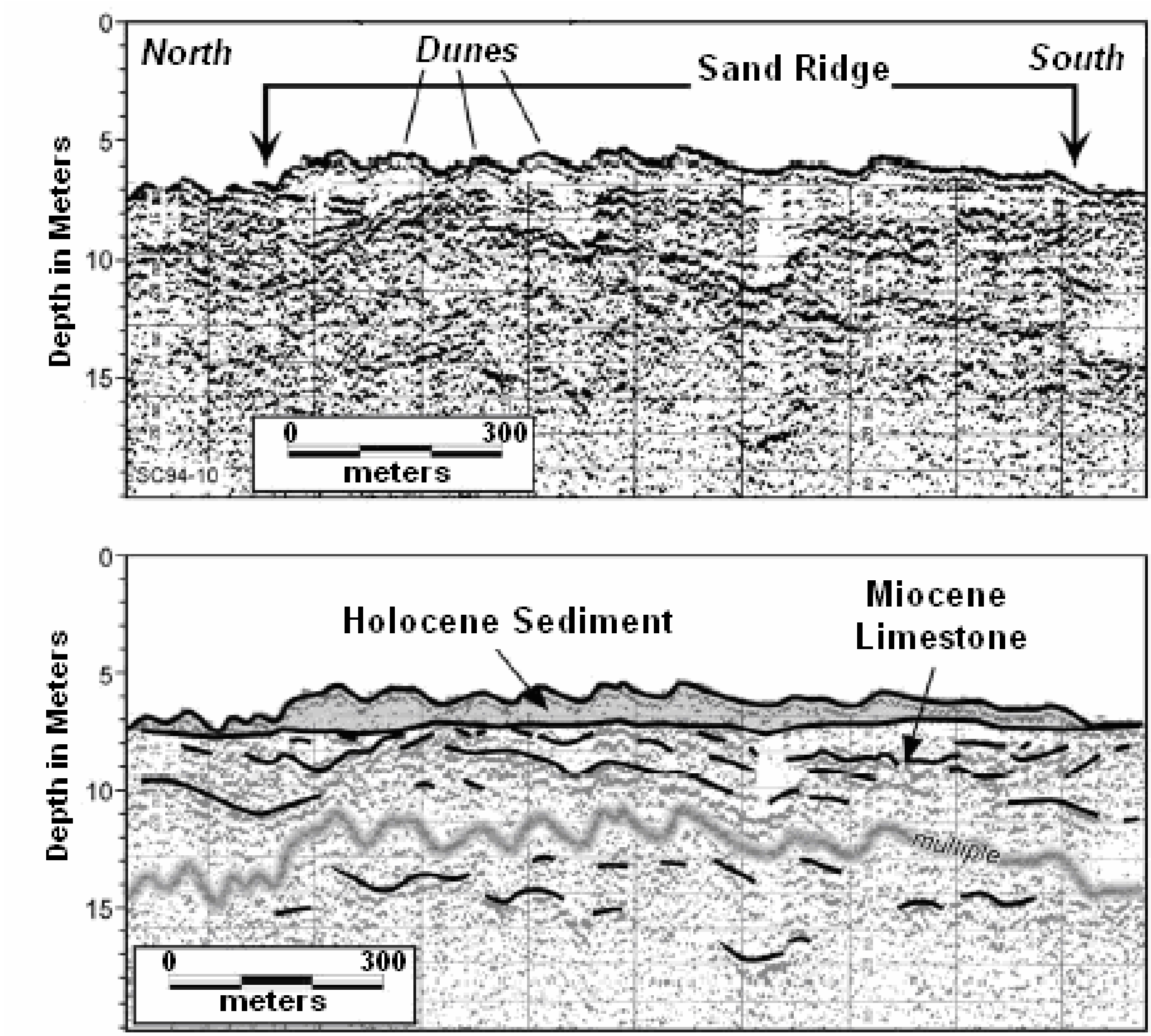


Figure 2-7. Seismic stratigraphy offshore of Indian Rock Beach north of Tampa Bay showing fields of large sand waves combining to form sand ridge topography (from Locker et al., 2003).

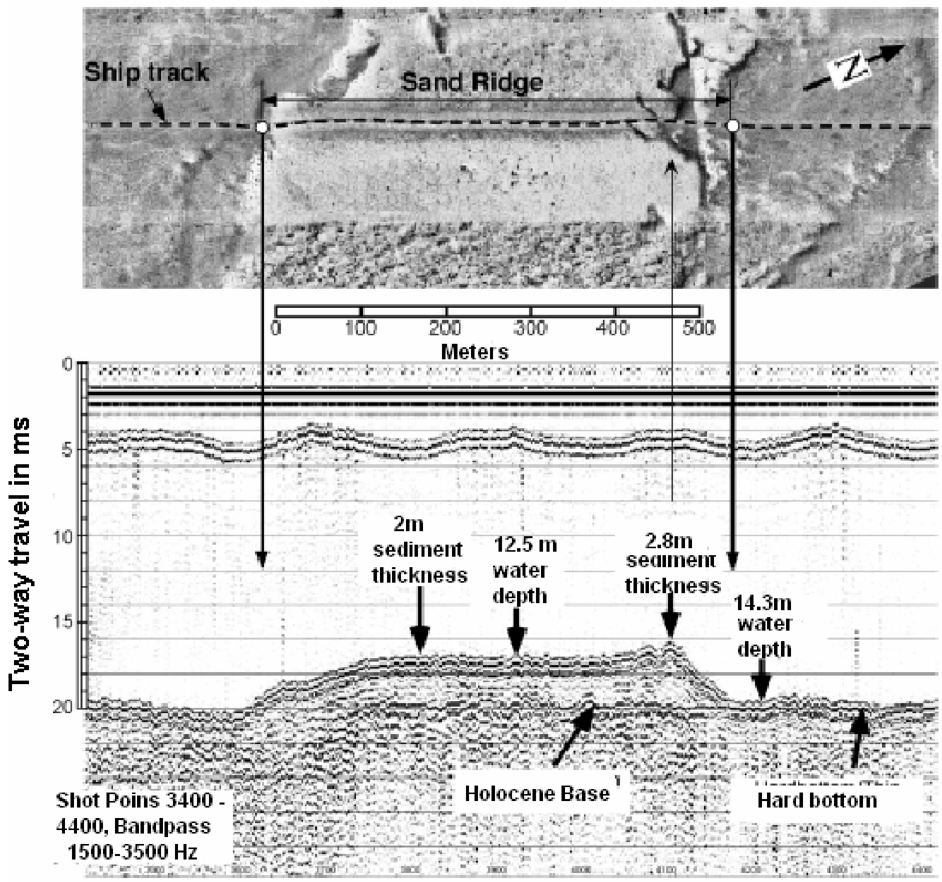


Figure 2-8. Side scan sonar and seismic cross-section records from a sand ridge located about 15 miles offshore of Indian Rocks Beach. Water depth at the crest of the ridge is about 40 ft (12 m) (from Howd et al., 2003).

South of Tampa Bay

The Holocene sediment thickness from Tampa Bay south to the Venice area is generally less than 2 m. In a few isolated nearshore areas, sediment thickness within distinctive sand ridges can reach 3 to 4m. These accumulations of sand may be in ebb shoals or nearshore ridges that are currently being accessed for beach quality sand. As in the areas north of Tampa Bay, some sand accumulates in ridges further offshore in 15 to 20 m water depths. Figure 2-9 shows the location of nearshore sand ridges being developed by Sarasota County to renourish the beaches of Venice, FL to the south.

The Holocene isopach south of Tampa near Sanibel Island is on average thinner than the ebb shoal deposits at the entrance to the Bay and areas further to the north. To explain regional sediment accumulation trends and understand the role of antecedent topography and sediment sources in controlling barrier island evolution and development of the transgressive Holocene shelf deposits, the USGS Research Group compared sediment accumulation trends with the slope of the inner continental shelf (Locker et al., 2003). Figure 2-10 shows the cross-shelf distribution of Holocene sediment thickness compared to the bedrock depth of each shelf section. The barrier island related accumulations are at a maximum in the 2 to 6 m bedrock depth interval, averaging 3 to 4 m in thickness. In both sections north and south of Tampa Bay the nearshore sediment wedge thins to less than 1 m on average of sediment thickness in the 10 to 15 m depth interval. Offshore of the entrance of Tampa Bay the ebb shoal extends sediment thicknesses greater than 1 to 2 m further seaward. However, in all areas of the central west Florida shelf minima in sediment thickness are reached offshore in 10 to 15 m depths. From Tampa Bay to the north, increases in average sediment thickness are found farther seaward at depths greater than 15 m, whereas south of Tampa Bay, the average thickness is low, although the maximum thickness of sand bodies consistently tends to be greater offshore as in areas north of the Bay. An overview of these trends in Holocene sediment thickness is shown in Figure 2-11 (Locker et al., 2003).

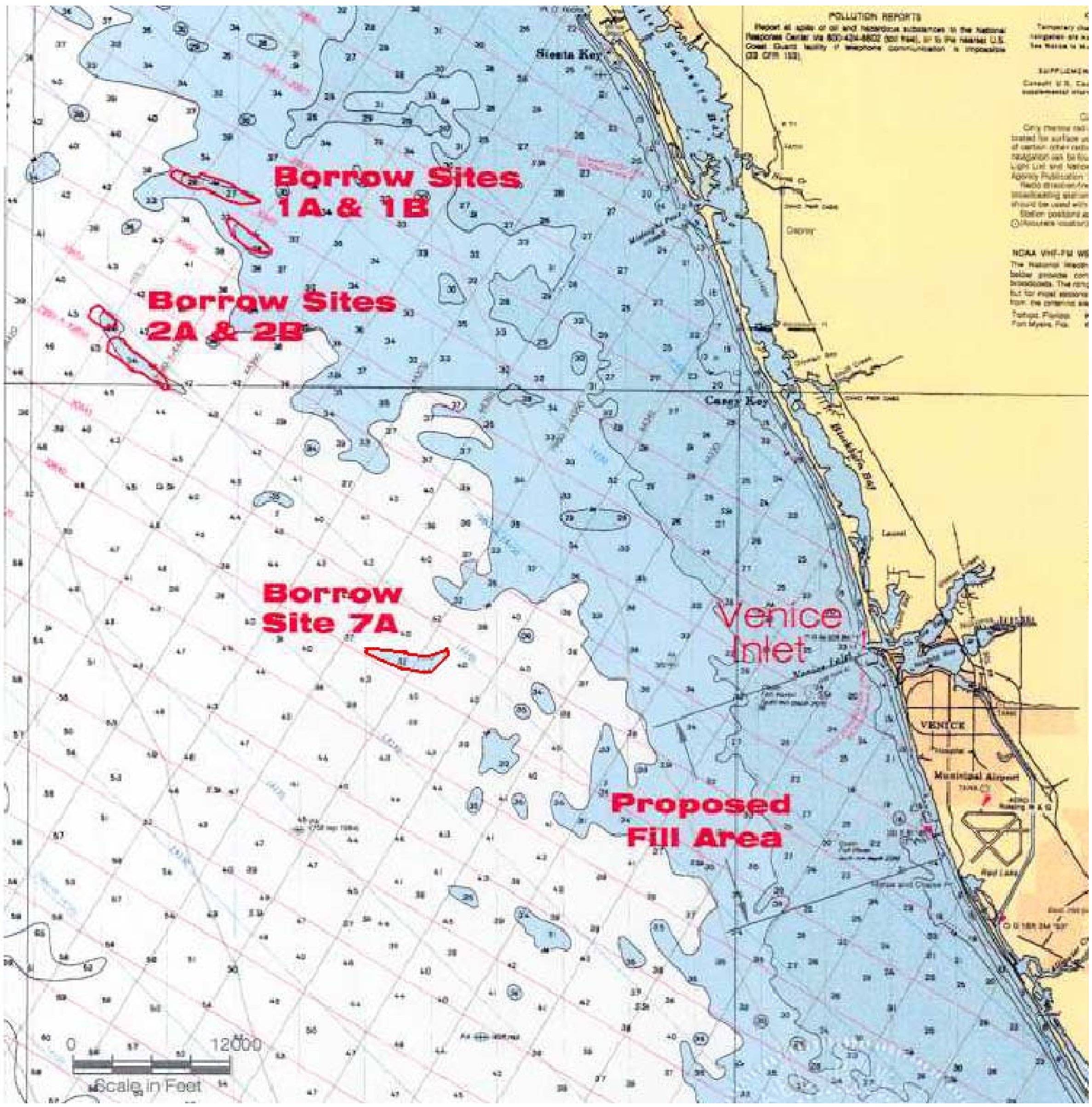


Figure 2-9. The location of sand ridges surveyed for beach quality sand by Coastal Tech, Inc. for Sarasota County. The proposed fill area is within the vicinity of Venice, FL (from Coastal Technology, Inc. report to Sarasota County, 2005).

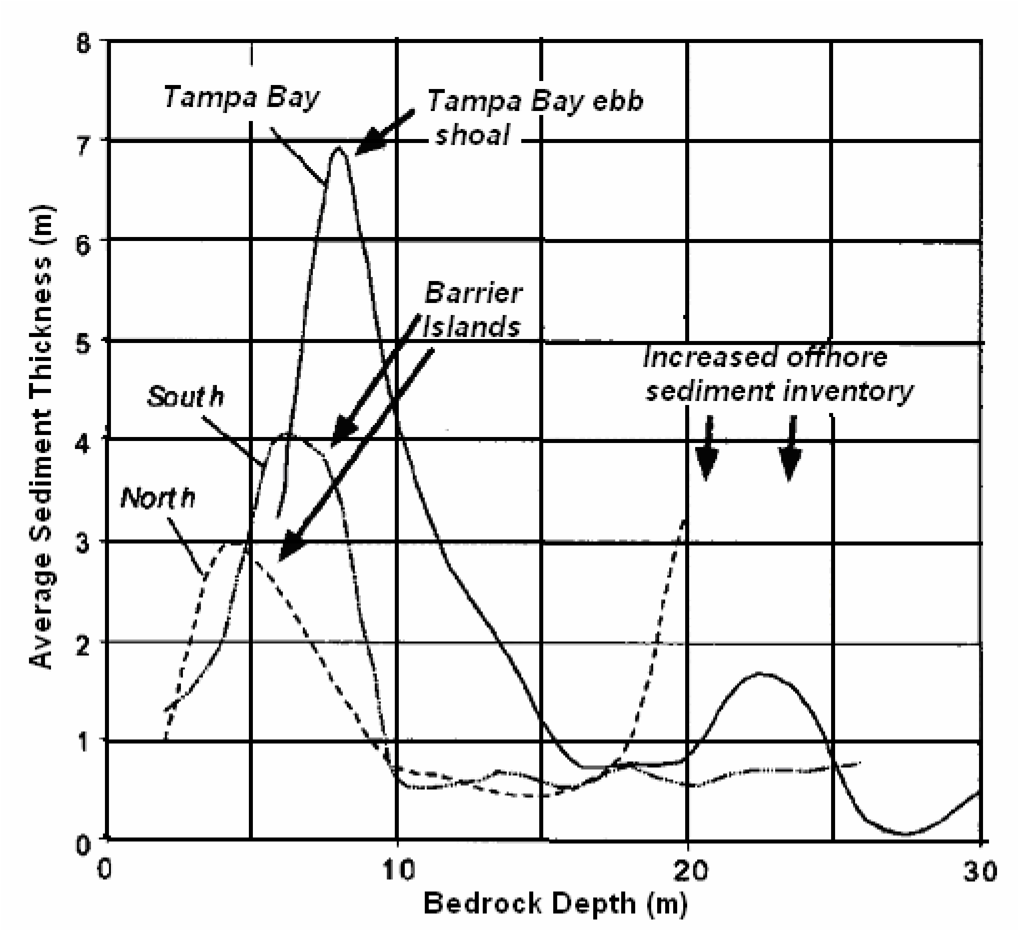


Figure 2-10. Plot of average Holocene sediment thickness versus bedrock depth, which marks the transgressive surface on which Holocene and modern sediments are deposited (from Locker et al., 2003).

2.3.3 Sand Ridge and Inter-Ridge Sediments

A major purpose of the current MMS project and work by the USGS and others along the west Florida shelf is to characterize sand-ridge resources in view of potential recovery for beach nourishment. Thus, it is important to review the patterns and trends of texture and composition of ridge and inter-ridge sediments. These patterns and trends were described in detail in many of the published papers and reports produced from the USGS west Florida projects (Locker et al., 2001b, 2002a; Brooks et al., 2003; Davis et al., 2003). Holocene sediments resulted from the redistribution and sorting of quartz sand during sea level transgression and the response to the open shelf hydrodynamic regime during the past few thousand years. Additional sediment sources included local production of carbonate material that is primarily molluscan in origin, and is reworked from pre-Holocene sequences exposed at the bathymetric surface.

Brooks et al. (2003) identified six Holocene sediment types and associated depositional environments, consisting of three back-barrier facies (organic muddy sand, olive-gray mud, and muddy sand facies) and three open-marine facies (well-sorted quartz sand, shelly sand, and black sand facies). Samples taken north of Tampa Bay typically consisted of medium-grained quartz sand facies including secondary amounts of coarse grained carbonate shell material. The open marine sandy sediments form most of the 1 to 3 m thick Holocene sand-ridge section. The quartz-sand facies were interpreted as deposited under open-marine conditions (Brooks et al., 2003).

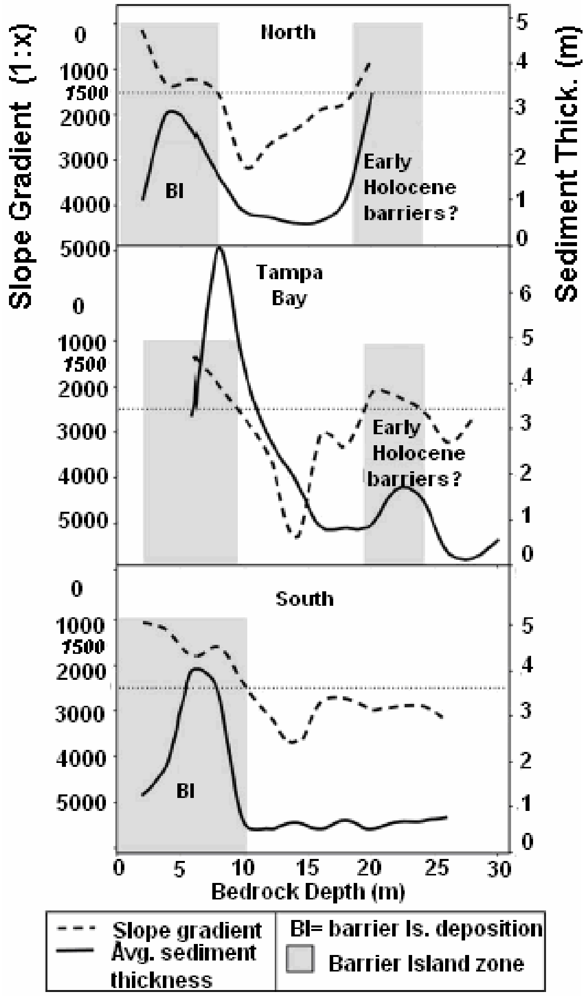


Figure 2-11. Plots depict relationship of Holocene sediment thickness to slope gradients for the three sections of the west Florida inner continental shelf. Slope gradients greater than 1:1500 correlate to thicker accumulations known, or inferred, to be barrier-island systems (from Locker et al., 2003).

Core samples recovered by the USGS project in the Tampa Bay area approached 5 m in thickness. Back-barrier facies, including mud and mud-rich sand containing burrows and lagoonal foraminiferal assemblages, were recovered. The offshore back-barrier facies were radiocarbon-dated at 8300 +/- 90 yr BP with a transition to open-marine facies that dated from 5900 to 7790 yr BP. Offshore of the Tampa Bay area, core borings penetrated facies similar to those described farther north. However, there is a trend for less sediment cover and an increase of blackened grains mixed with the open-shelf, well-sorted quartz sand. Additionally, the base of the Holocene contains some muddy facies that are typical of back-barrier/lagoonal deposits (Brooks et al., 2003; Locker et al., 2003).

Offshore core recovery south of Tampa Bay, where the Holocene sediment thickness is usually less than 2 m, carbonate sand and gravel with secondary amounts of quartz sand are common. Some increase of quartz sand content in the inner 3 km portion of the shelf was documented (Locker et al., 2001a; Brooks et al., 2003).

In contrast to the sand ridge deposits, inter-ridge trough areas are characterized by coarse grained and gravel-sized carbonate skeletal material identified from the high-backscatter in sonar records and from grab samples (Brooks et al., 1998; Edwards et al., 2003; Harrison et al., 2003). Such a segregation of grain populations is common in sediment starved shelf environments (Riggs et al., 1998). However, exceptions to this topography and texture association can be found in the southern portion of the study area.

A comparison of nearshore sand ridges in the Northern (Indian Rocks Beach) and Southern (Sarasota) areas revealed differences in sedimentary facies relative to ridge morphology (Locker et al., 2003). The sand ridges north of Tampa Bay displayed low side scan backscatter associated with the full bathymetric expression of the sand ridges and across the ridge's crest due to a more, uniform texture for these sand bodies (Harrison et al., 2003). In contrast, off Sarasota, a significant variation in sediment texture occurs within the bathymetric expression of a sand ridge. Twichell et al. (2003) found an abrupt change in side-scan backscatter and sediment texture at the ridge crest, characterized by the presence of coarser-grained carbonate rich sediment on the northern flank and finer-grained quartz sand on the southern flanks. Twichell et al. (2003) suggested that current winnowing of the northern flanks of the sand ridge might control the sharp textural transition in the Sarasota area, whereas off the Indian Rocks Beach headland, the net effect of tides, wave shoaling, and seasonal storms may be a more balanced, bidirectional sediment transport (Yang and Weisberg, 1999; Yang et al., 1999). The physical oceanography and hydrodynamic regime of the west Florida shelf related to sand ridge dynamics is discussed in Section 2.4 of this report.

In the very southern portion of the west–central Florida shelf, which was beyond the scope of the recent USGS studies, less is known about sand-ridge sediments. In areas south of Venice, FL to the Naples, FL, area topographic relief suggests limited sand ridge development and thus a limited supply of beach quality sand except where ebb shoals have developed in the nearshore and littoral zone. This is consistent with the conclusion of the USGS study that indicate barrier island development in the southern areas was absent or minimal, leaving a limited supply of Holocene clastic sediments in the wake of the Holocene transgression (Brooks et al, 2003, Locker et al., 2003). However, some sand ridge fields do occur in the MMS study area well south of Tampa Bay. Survey work conducted for Collier County by Coastal Planning and Engineering, Inc. (CPE, 2005 identified two substantial sand ridge deposits. Figure 2-12 shows the location of the T1 (northern portion dredged in first half of 2006) and T2 ridges being targeted for beach quality sand. Both of these locations are in Federal waters and are included in the current MMS project to evaluate the potential for physical and biological impacts. The local bottom topography indicates that the T1 and T2 features are part of a local field of sand ridges extending offshore from the shoreface of Sanibel Island. Figure 2-13 shows a seismic cross-section through the T1 ridge, which is a mixture of quartz and carbonate sands in the medium grain size range. Another apparent field of ridges may be located offshore of the Naples area. One of these ridges, located within state waters is currently under evaluation for recovery of beach quality sand (Finkl et al., 2004). None of these areas has been studied on a regional basis and the extent and texture of Holocene facies is unknown. The southern areas covered by this project can be termed as a region of sand-starved ridges, since the source of Holocene sediments accumulated in these features is very limited and the inter-ridge areas are likely to be semi-lithified carbonate rocks of Oligocene to Pleistocene age (Harrison et al., 2003). In the case of the T1 and T2 ridges, their development on the carbonate platform may be a related coastal headland, suggesting some genetic relationship. An elevated rock terrace extending from the headland supports the current location of Sanibel Island as well as the T1/T2 ridges in shallower water compared to the surrounding shelf, allowing for more influence by currents and waves that accumulate the sand deposits into a series of large-scale bedforms (Harrison et al., 2003).

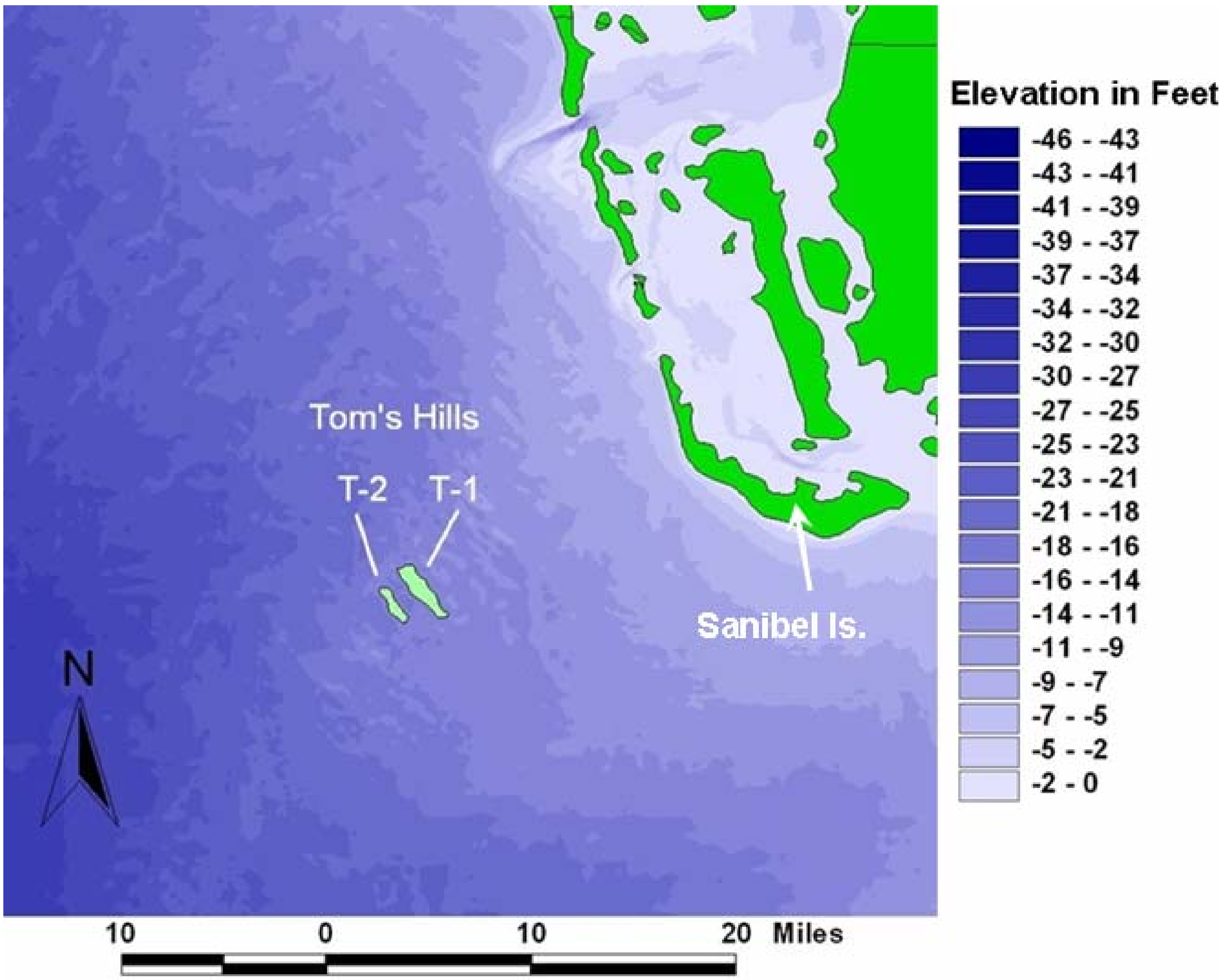


Figure 2-12. Location of the T1 and T2 (Tom's Hills) sand ridges approximately 13 miles west-southwest of Sanibel Island.

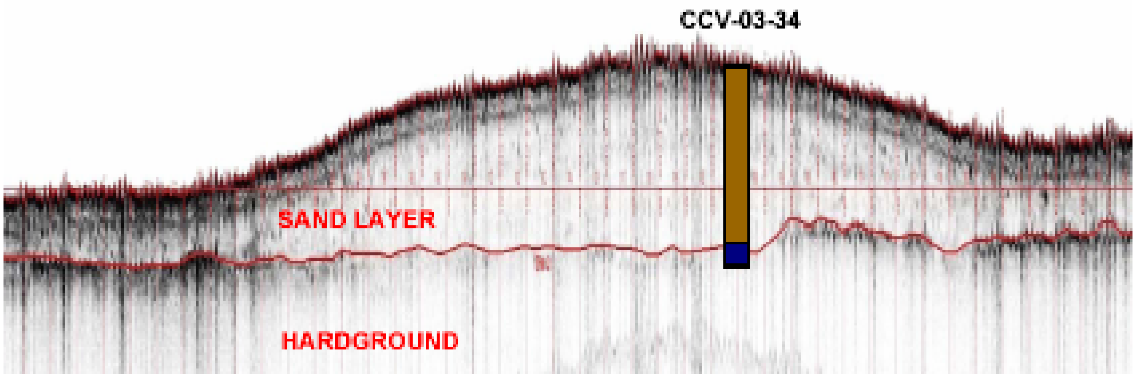


Figure 2-13. A seismic cross-section through the T1 sand ridge. Maximum relief is approximately 20 feet. Location is shown in Figure 2-12 (from Finkl et al., 2004).

2.3.4 Sand Ridge Genesis

The origin of the offshore sediment distribution patterns and, in particular, the origin and development of sand ridges on the west Florida shelf is not fully understood. The USGS study (Locker et al., 2003) indicated that sediment deposition is associated with the combined processes of Holocene transgression and modern hydrodynamic regime, but the dominant process may be the reworking by open shelf hydrodynamics. Barrier-island superstructure deposits have not been identified in the USGS or other samples and appear unlikely to be preserved as original depositional units (Locker et al., 2003). Barrier-island superstructure deposits have not been identified in the USGS and other samples and appear unlikely to be preserved as original depositional units (Locker et al., 2003). Backbarrier sediments have been identified from offshore areas north of Tampa Bay and may be largely absent south of the Bay entrance. The USGS concludes that the development of barrier islands has resulted in the greater occurrence of Holocene sand volume in some offshore areas as described above. The development of sand ridges in offshore areas not influenced by barrier islands indicates that shelf hydrodynamic processes have played an important role in the origin and maintenance of ridge deposits.

Investigations of the Eastern U.S. Atlantic continental shelf have emphasized barrier-island retreat and associated models for the origin of sand ridges. Shoreline retreat mechanisms include shoreface-attached ridges and ebb-tidal delta retreat paths (Duane et al., 1972; Swift et al., 1972; Stubblefield et al., 1984; McBride and Moslow, 1991; Snedden et al., 1994, 1999). Other studies consider open shelf formation unrelated to shoreline retreat (Stubblefield et al., 1984; Swift and Rice, 1984; Tillman and Martinsen, 1984). Once the sand ridges are generated, the open shelf hydraulic regime is considered important for maintaining sand-ridge systems (Huthnance, 1982; Trowbridge, 1995).

Reports by Edwards et al. (2003) and Twichell et al. (2003) describe possible origins for local sand-ridge systems of the west Florida shelf and cite evidence both for and against shoreface related origins. From a regional perspective, the initial ridge development phase is only reflected in the sediment volume now contained within the sand ridges. The distribution of sand ridges suggests that they form directly on an open, shallow-marine inner shelf, with no influence from barrier-island migration or erosional shoreface retreat. The very low-gradient areas of the west Florida shelf (slopes less than 1:1500) likely transitioned from marsh and seagrass to open-marine environments during sea-level transgression without any intervening high-energy beach transgression. This scenario is supported by core samples showing a transition from low- to higher-energy sedimentary facies without evidence for a ravinement surface (Edwards et al., 2003). The sand ridges which extend north of the west-central Florida barrier-island system, and are located seaward of the open marine marsh and seagrass-dominated coastline, appear to be developing directly from these earlier low-energy environments, suggesting a sand-ridge origin independent of barrier-island migration and erosional shoreface retreat. Additionally, many areas within this study area, such as much of the Southern Province shelf and portions of the Northern Province in 10 to 15 m water depth, could have similarly evolved (Edwards et al., 2003).

Figure 2-14 is a summary of the two models of sand ridge evolution described by Edwards et al. (2003). In Model 1, sand ridges originate on an open shelf sand ridge. The evolution begins with seagrass beds on a low gradient open shelf lagoon (A). As sea level rises, the seagrass beds disappear and sand ridges begin to form under the hydrodynamic regime of the shallow open water storm-dominated shelf environment. Sediment sources were sand reworked from older underlying deposits. In areas where the shelf slope exceeds 1:1500, the antecedent topographic control is exerted and a wave-dominated littoral zone develops where coarse-grained sediment accumulation leads to barrier island origin (B). In the final stage of development (C), sand-ridge fields are fully formed in an energetic shelf environment along with the barrier island and modern lagoon systems.

In conceptual Model 2 (Figure 2-14), sand ridges develop as part of a migrating barrier island system. The evolution begins about 8000 year BP with a migrating barrier island present on a high gradient shelf with a slope greater than 1:1500. Back-barrier seagrass beds dominate the lagoon environment (D). By 4000 years BP the barrier island system has migrated landward leaving behind a ravinement surface on which sand-ridge deposits begin to develop (E). Sand sources were a combination of re-worked barrier island littoral sands and re-working of sands from underlying sediments as the ravinement surface formed. In the final development stage, the modern barrier island systems continue to evolve with the associated sand ridge deposits deriving their source from littoral sands and possibly older sediments re-worked by the hydrodynamic regime of a storm-dominated energetic shelf (F).

2.3.5 Regional Depositional Model

A regional synthesis of the controls on development of Holocene sedimentary units and associated shelf surface morphology was developed by the USGS Research Group (Locker, et al., 2003). The regional sediment thickness and slope gradient data show a positive correlation between increased gradients of the bedrock (transgressive surface) and increased sediment thickness. Thicker sediment accumulations are positioned over the more steeply inclined transgressive surface. Lower gradients of the transgressive surface correlate with thinner Holocene sediment accumulations. This indicates a first-order control by bedrock topography on the development of Holocene sedimentary environments that is distinctive from controls exerted by sea level rise and sediment supply. One of the overall goals of the USGS project was to provide a set of guidelines and geologic models that can be used to locate beach quality sand on the inner continental shelf. The USGS Research Group developed a 3-phase model for the origin and development of Holocene depositional environments. This model can be used as a tool for targeting nearshore and offshore areas that are likely to yield beach quality sand. The USGS model was used as a guide to locate the sand ridges that were selected for evaluation in the current MMS study.

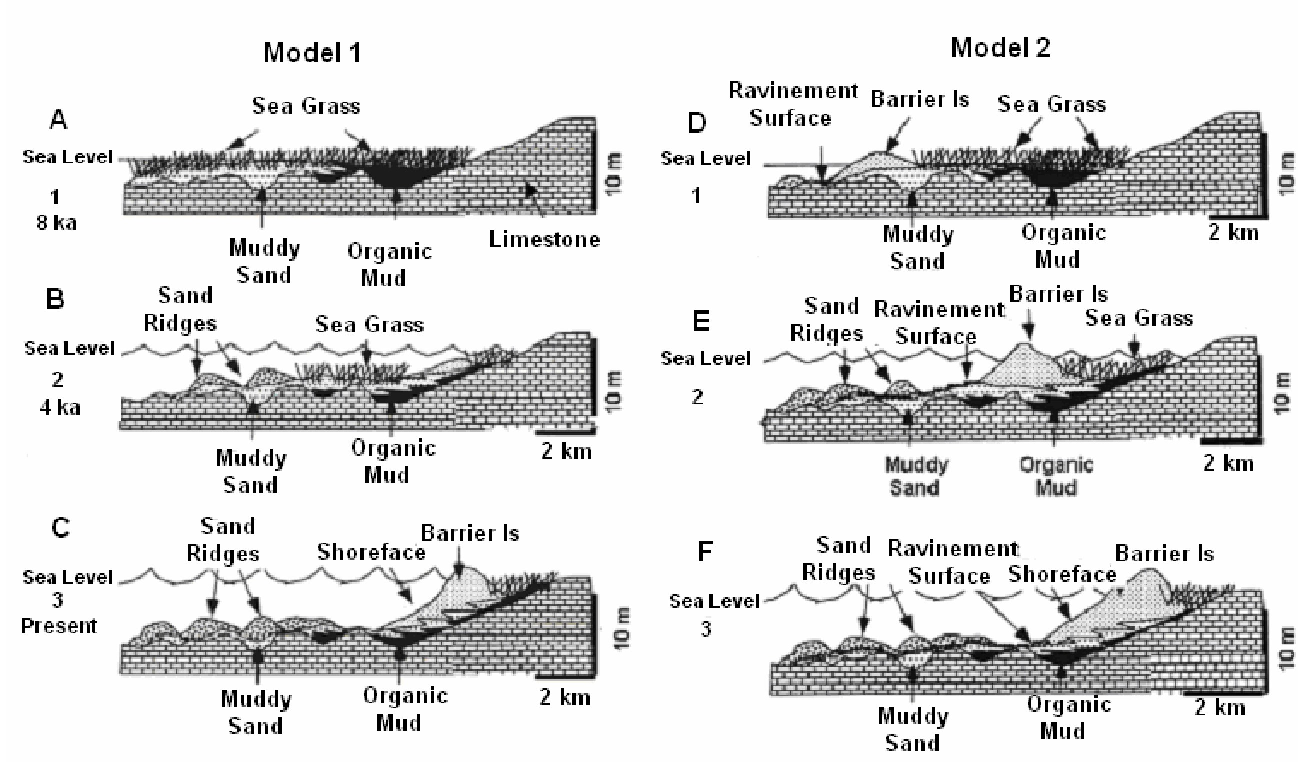


Figure 2-14. Conceptual models of sand ridge and barrier island development on a shallow, low gradient shelf originally dominated by seagrass beds (from Edwards et al., 2003).

The USGS 3-phase conceptual model for evolution of the west-central Florida shelf and coastal system is based on sediment-thickness data collected by the USGS-sponsored research described as well as earlier studies. The existence of earlier Holocene barrier islands off west-central Florida is not confirmed for all locations because of reworking by open marine processes. However, mid-Holocene barrier systems are inferred based on the presence of back-barrier sediments in cores. Back-barrier and open, low-energy marsh coastlines are thought to produce similar facies patterns (Hine et al., 1988; Brooks et al., 2003). It is most likely that the west Florida coastal region experienced a combination of barrier and open shelf/marsh coastlines, both spatially and temporally.

In the early Holocene Phase I of the USGS conceptual model, barrier-island development at elevations of -15 to -20 m below modern sea level probably occurred in areas north of Tampa Bay and perhaps extended into the Tampa Bay area (Brooks et al., 2003). The present greater abundance of quartz sand and back-barrier sediment across the northern shelf region is consistent with this pattern. Barrier islands would not have formed until a few meters of accommodation space had been created over the areas of steeper gradient (Locker et al., 2003). According to the USGS analysis these early barriers did not migrate across the shelf, but were drowned as the system became a low gradient, low-energy, open-marine shelf similar to the present-day Big Bend region north of Anclote Key. To the south, lower shelf gradients did not favor barrier-island formation, and back-barrier facies are absent from the low-gradient area south of Tampa Bay entrance. An open rocky or marsh coastal system likely supported the active bio-erosion of the Miocene bedrock to produce the black sand facies now found in the area (Locker et al., 2003). The estuarine/bay system may not have existed then, or was only a broad open embayment.

During the mid-Holocene Phase II of the USGS conceptual model, the low-gradient inner shelf experienced gradual drowning of an open-marine, low-energy, seagrass-dominated environment, barrier islands are less likely to have occurred (Brooks, et al., 2003; Locker et al., 2003). The low-energy seagrass-stabilized open shelf transitioned to more active sediment transport, with sand ridges forming when the water depth exceeded some undetermined depth limit. South of Tampa Bay with the deeper bedrock elevations, the sand ridges probably began to develop earlier by reworking from limited relict sediment supplies. North of Tampa Bay, the offshore barriers were drowned and underwent reworking and dispersal. The modern Tampa Bay embayment developed, and the increasing tidal exchange began to build ebb-tidal deposits on the inner shelf at the mouth of Tampa Bay.

During the late Holocene (3000 years BP to present) Phase III of the USGS model, the modern barrier-island system along the west-central Florida coast developed from the combination of the decreasing rate of sea-level rise with the antecedent topographic to control barrier island position. The Tampa Bay estuarine system expanded with shoaling at the mouth of Tampa Bay caused by ebb-shoal deposition. The extensive development of sand barriers around the mouth of Tampa Bay reflects a redistribution of sediments, which were trapped within the expanding ebb-tidal system as the estuarine tidal prism increased in size (Locker et al., 2003).

Locker et al. (2003) summarize the major findings by the USGS-USF researchers and provide more details on the sedimentology, structural geology, and evolution of the central west Florida shelf from Anclote Key to the region of Venice, FL. South of this area sand search surveys by the various counties and their consultants (CPE, 2001; S.E.A., 2002) provide more localized information on specific sand resources.

2.4 Historical Bathymetric Changes

Historical records and recent topographic data collected by Federal agencies are in a Web accessible database maintained by the National Geophysical Data Center (NGDC, http://www.ngdc.noaa.gov). This database contains bathymetric data sources from the U.S. National Ocean Service Hydrographic Database, the U.S. Geological Survey (USGS), Monterey Bay Aquarium Research Institute (MBARI), USACE LIDAR (SHOALS), as well as academic institutions. These data can be acquired as gridded data sets within user selected geographic coordinates or can be downloaded along the original survey track lines. For this project, a thorough search for all available bathymetric data was completed.

The track line patterns and survey dates within the west Florida study area are shown in Figure 2-15. Unlike the east Florida coast and, in general, the U.S. East Coast, surveys of the Florida Gulf Coast are sparse in space and time. Among the several regional surveys that have been completed, only surveys that geographically overlap can be used to examine evolution of sand ridge morphology. Unfortunately, surveys in the area of the T1 and T2 Shoals are very limited. To the north in the Siesta Shoal areas, survey lines are only available for one date in the late 19th century making it impossible to resolve long-term morphologic changes. To the south of the T1/T2 Shoal area, there is an area of overlap with survey lines available from two periods over a long enough time frame to resolve long-term morphology change (Figure 2-16). This area is located in the sand starved region described by Edwards et al. (2003). This fact combined with the sparse data coverage particularly from 1877-88 make it difficult to detect topographic change.

Figure 2-16 shows the net topographic difference over a period of approximately 75 years between the 1877-88 survey and the 1955-61 survey. The net difference was determined by producing an interpolated grid of data points from each set of survey data and calculating the difference between the interpolated grids. A major limitation of the calculation is that data from 1877-88, although having some overlap with the 1955-61 data, has very widely spaced track lines (see Figure 2-16). The overlap area is well south of the T1/T2 shoal. The computed changes in topography as shown in Figure 2-17 predominantly shows a net decrease of depth on the east side of the area and a net increase in depth on the west side.

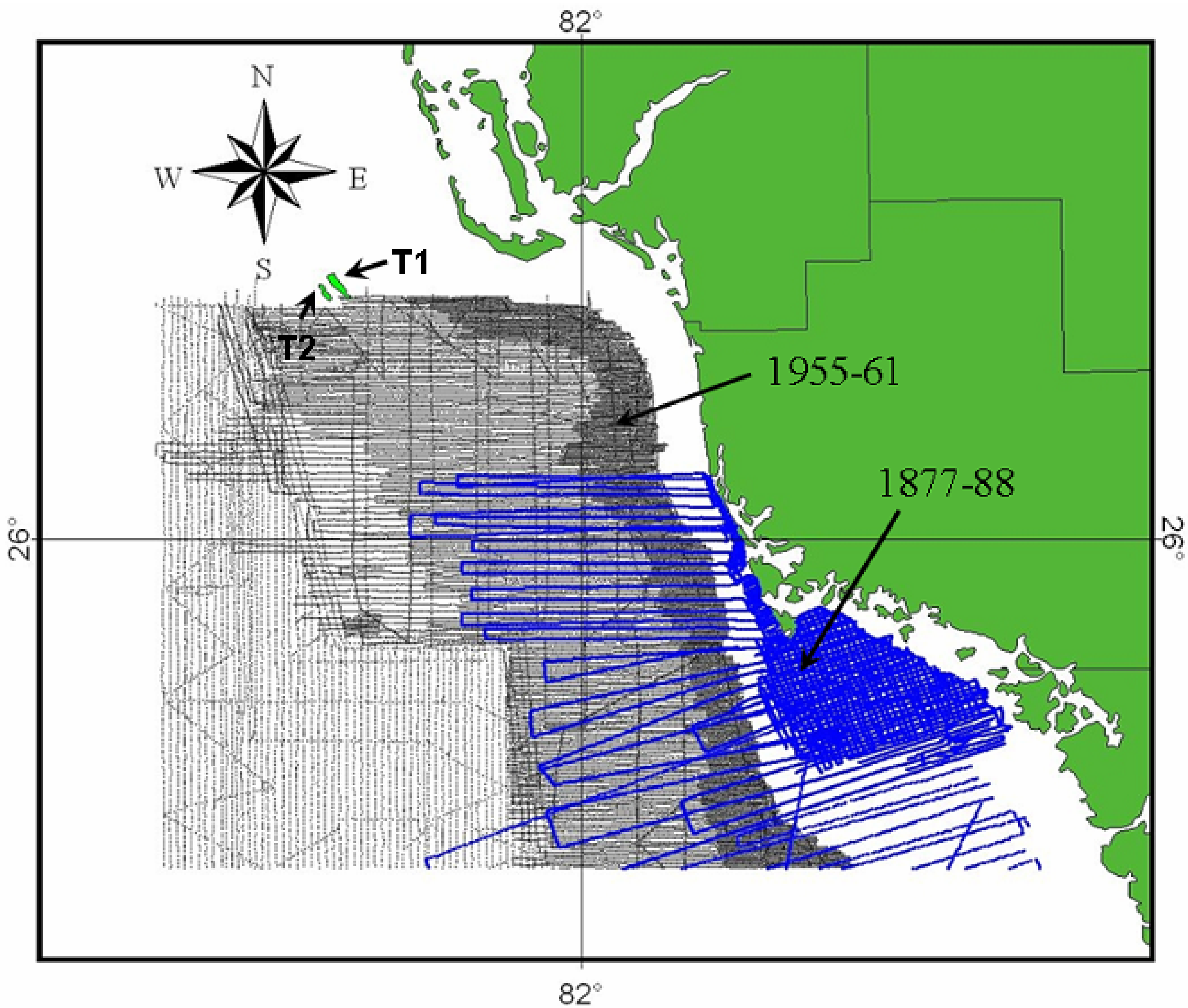


Figure 2-15. Pattern of survey tracklines from the period 1877-88 (blue) and the period 1955-61 (black) with areas of overlap to the south of the T1 and T2 Shoals.

The frequency distribution of change in each depth range class shown in Figure 2-16 is shown in Figure 2-17. The distribution shows that the changes are clustered in a range of -3 to +3 feet. Given the sparse data coverage, and the interpolation among widely spaced data track lines (see Figure 2-15) it is likely that long-term depth changes cannot be resolved with confidence. Furthermore, in the sand-limited areas of the southwest Florida coast, real changes over the past century are likely to be small and data are dependent on the accuracy and resolution of the survey methods used to collect bathymetric data.

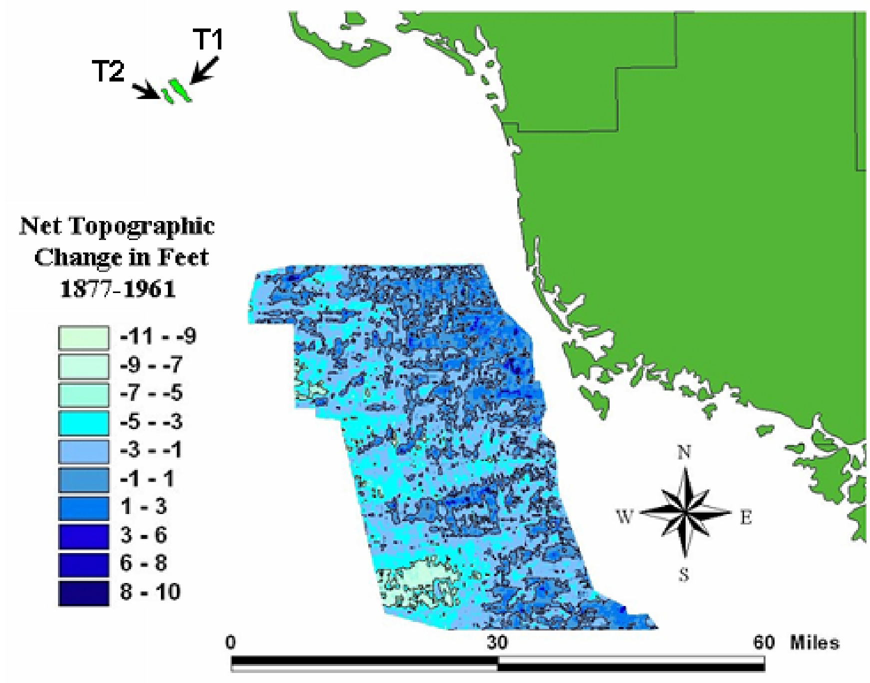


Figure 2-16. Net differences between interpolated topographic surfaces calculated from the overlap areas of the 1877-88 survey data and the 1955-61 survey data sets.

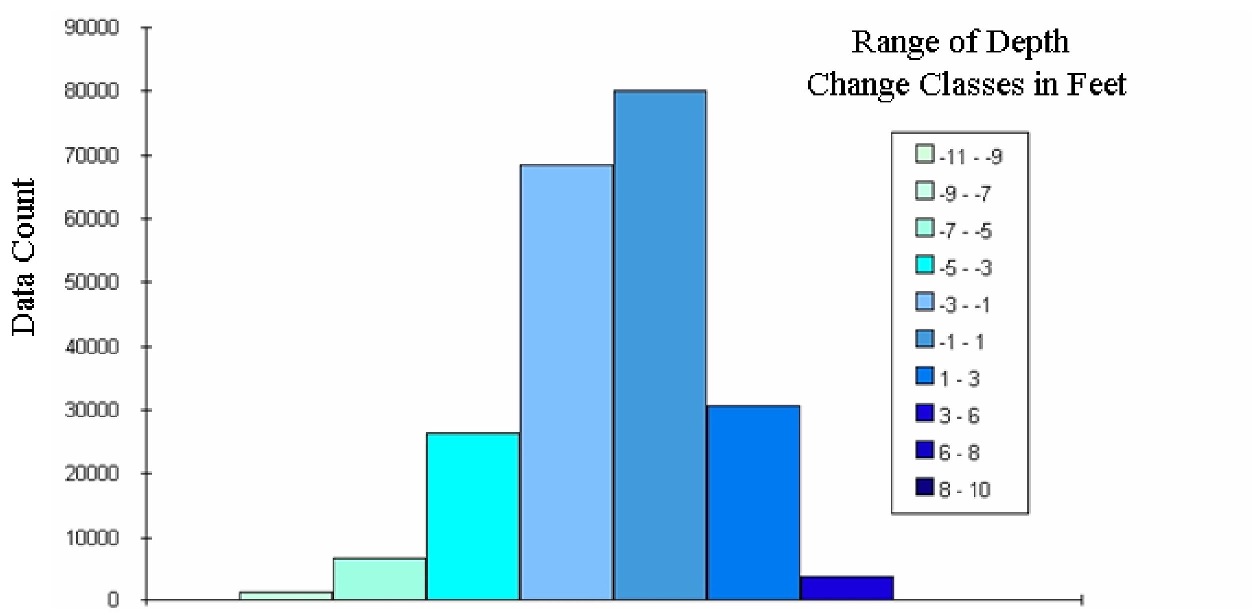


Figure 2-17. Frequency distribution of net topographic change data shown in Figure 2-16.

2.5 Physical Oceanography

On a regional basis, the west Florida continental shelf is influenced by ocean basin processes operating in the Gulf of Mexico and processes that are amplified over the gently sloping topography that extends approximately 200 km from the shoreline to the shelf break (see Figure 2-1). The west Florida shelf is a semi-enclosed area, bounded by the Florida Keys on the south and by the Florida Panhandle to the north. The shelf circulation is subject to the seasonally varying wind stress, buoyancy inputs from freshwater and thermal structure, and the influence of the Loop Current that enters the Gulf of Mexico through the Yucatan Channel and exits as the Gulf Stream through the Florida Straits (Yang and Weisberg, 1999). Figure 2-18 shows the regional configuration of the Loop Current, Florida Current, and the formation of the Gulf Stream as the Florida Current exits the Straits of Florida. Figure 2-18 is based on output from the Florida Ocean Model (Zarillo and Yuk, 2001), which is a terrain following model designed for numerically stable calculations over sharp topography characteristic of continental margins.

The Loop Current is apparent from sea surface temperature observations derived from Advanced Very High Resolution Radiometer (AVHRR) imagery in the winter when the temperature gradients are sharp (Figure 2-19). The Loop Current originates outside the Gulf of Mexico. The North Equatorial Current, which is the southern leg of the North Atlantic subtropical gyre, flows west into the Caribbean Sea. These waters then enter the Gulf of Mexico through the Yucatan Channel forming the Loop Current. This current makes a clockwise loop as it moves through the Gulf and exits through the Straits of Florida. The Loop Current flux and patterns are variable and its northern extent changes with time, producing warm-core eddies that spin off with a periodicity of about 13 months (Sturges, 1994) providing oligotrophic waters to the western portion of the Gulf.

As the Loop Current extends north and east, its influence on the west Florida shelf increases. For example, by providing higher dynamic height near the Louisiana coast, it effectively drives relatively fresh, nutrient rich waters from the Mississippi Delta onto the west Florida shelf. The Loop Current does not flow onto the shelf, but waters from the Loop Current may be transported onto the shelf via the formation of smaller scale filaments or by Ekman transport. Thus, the Loop Current can be an important factor influencing the shelf circulation without actually flowing onto the shelf (Weisberg et al., 1996).

Biological phenomena that occur within the west Florida shelf region may be related to shelf circulation. These phenomena include episodic, seasonal blooms of (red tide) toxic dinoflagellates thought to originate at midshelf (Steidinger, 1983; Vargo et al., 1987), the seasonal formation of high-concentration pigment plumes near the shelf break (Gilbes et al., 1996), and the seasonal succession of fish recruitment (Yang and Weisberg, 1999). The recent studies of sand ridge sediments described in other sections of this report also indicate the influence of seasonally varying wind-derived currents on sand transport and textural pattern of modern sediments (Locker et al., 2003). Yang and Weisberg (1999) examined the major features of circulation on the west Florida shelf using the Princeton Ocean Model (POM; Blumberg and Mellor, 1983).

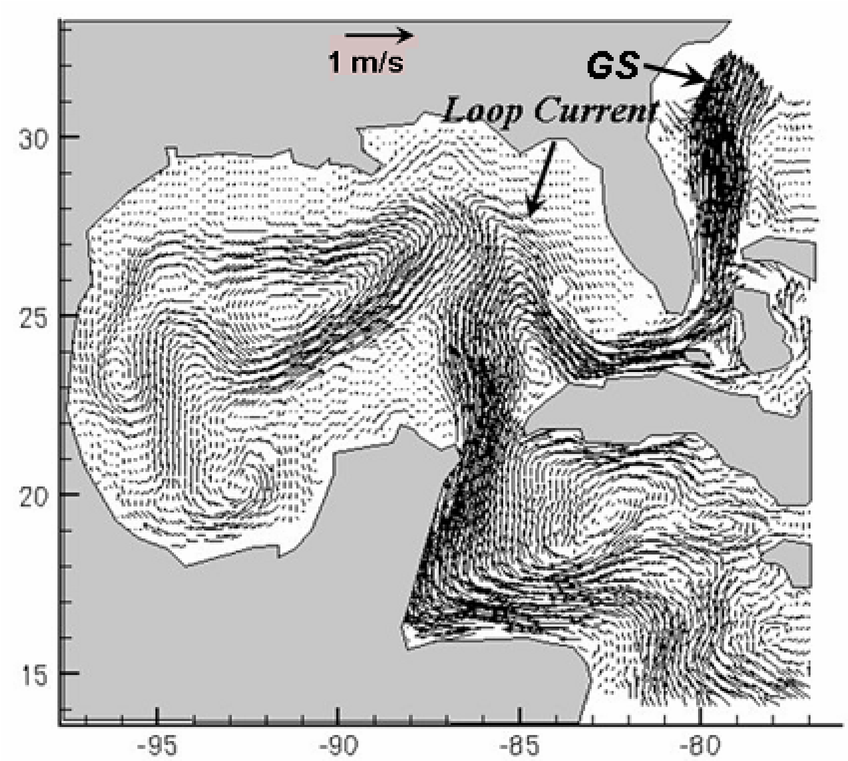


Figure 2-18. Prediction of the surface current field in the western Caribbean basin and Gulf of Mexico from the Florida Ocean Model (Zarillo and Yuk, 2001). GS = Gulf Stream

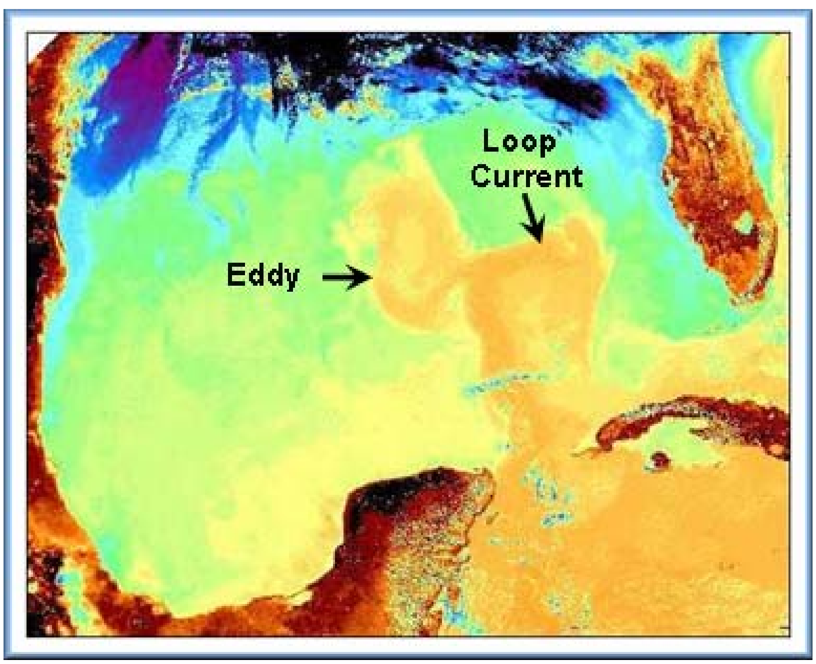


Figure 2-19. AVHRR-derived sea surface temperatures in the Gulf of Mexico marking the position of the Loop Current and a warm core eddy positioned to the north of the main current. The composite image is from the NOAA-National Environmental Satellite and Data Service (NESDIS).

2.5.1 Tides and Sea Level

The tides in the Gulf of Mexico are influenced by the scale and geometry of the Gulf, which can be described as semi-enclosed small ocean basin connected to the Caribbean through the Yucatan Straits and to the Atlantic Ocean through the Straits of Florida. These straits, although wide and deep, do not allow for strong co-oscillation and large tides in the Gulf. However, certain tidal constituents are amplified by shoaling that occurs over wide continental shelves like the west Florida shelf. The natural period of the Gulf favors the diurnal frequency and thus the diurnal K_1 tidal constituent is larger in amplitude over the basin compared to amplitude of the M_2 semidiurnal tide. The M_2 semidiurnal tide is amplified over the wide west Florida continental shelf. The tides of the inner shelf and coastal areas have a distinctive diurnal inequality characterized as semi-diurnal. The major features of the tides in the Gulf basin have been described through various basin-wide modeling efforts. Westernick et al. (1992) applied the Advanced Circulation Model for Oceanic, Coastal, and Estuarine Water or ADCIRC to model the tides. He and Weisberg (2002) applied the Princeton Ocean Model (POM) to investigate the tides over the west Florida shelf. A successful strategy to enhance the accuracy of coastal ocean circulation models and prediction of tides has been the use of increasingly larger computational domains (Mukai et al., 2002). Spatially detailed predictions of tidal constituents are now available for shelf and coastal areas of the Gulf of Mexico as well as the Atlantic Ocean (Mukai et al., 2002).

The ADCIRC finite element model has been used to quantify tidal phenomenon in the Gulf of Mexico including the west Florida shelf along with the U.S. East Coast. Figure 2-20 shows the North Atlantic Computational domain of the ADCIRC model application used to develop the East and Gulf Coast Tidal Database known as Eastcoast 2001 (Mukai et al., 2002). The tidal database is one of the data sources used to drive the modeling schemes applied to characterize the MMS study area on the west Florida shelf. This database was developed to allow surface-water elevation and currents to be quickly and easily defined in open waters within the Western North Atlantic Tidal (WNAT) domain. The WNAT domain encompasses the Western North Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. The database defines the computed elevation and velocity amplitude and phase for the O_1, K_1, Q_1, M_2, S_2, N_2, and K_2 astronomical tidal constituents as well as the steady, M_4 and M_6 overtides (Mukai et al., 2002). The model domain as shown in Figure 2-20 applies 254,629 nodes and 492,182 elements. The Eastcoast 2001 domain was forced on the 60-deg west meridian open boundary with O_1, K_1, Q_1, M_2, N_2, S_2, and K_2 tidal amplitudes and phases interpolated onto the open ocean boundary nodes using data from Le Provost’s 1995 global model (Le Provost et al., 1998).

He and Weisberg (2002) used a combination of the POM and in situ measurements to examine the principal semidiurnal (M_2 and S_2) and diurnal (K_1 and O_1) tidal constituents. The measurements included water levels at the coast and currents along the coastline and across the shelf. The model extended from west of the Mississippi River to the Florida Keys with an open boundary forced by a global tide model. Standard barotropic tidal analyses were performed for both the data and the model, and quantifiable calibration metrics are provided for comparison. Based on these comparisons the authors presented co-amplitude and co-phase charts for sea level and velocity hydrographs for currents. The semidiurnal constituents were found to be spatially variable, whereas the diurnal constituents were spatially uniform. Areas south of Apalachicola Bay, including the MMS study area, were found to have well developed semidiurnal tides according to model results, but in coastal areas west of the Apalachicola Bay diurnal tides dominate.

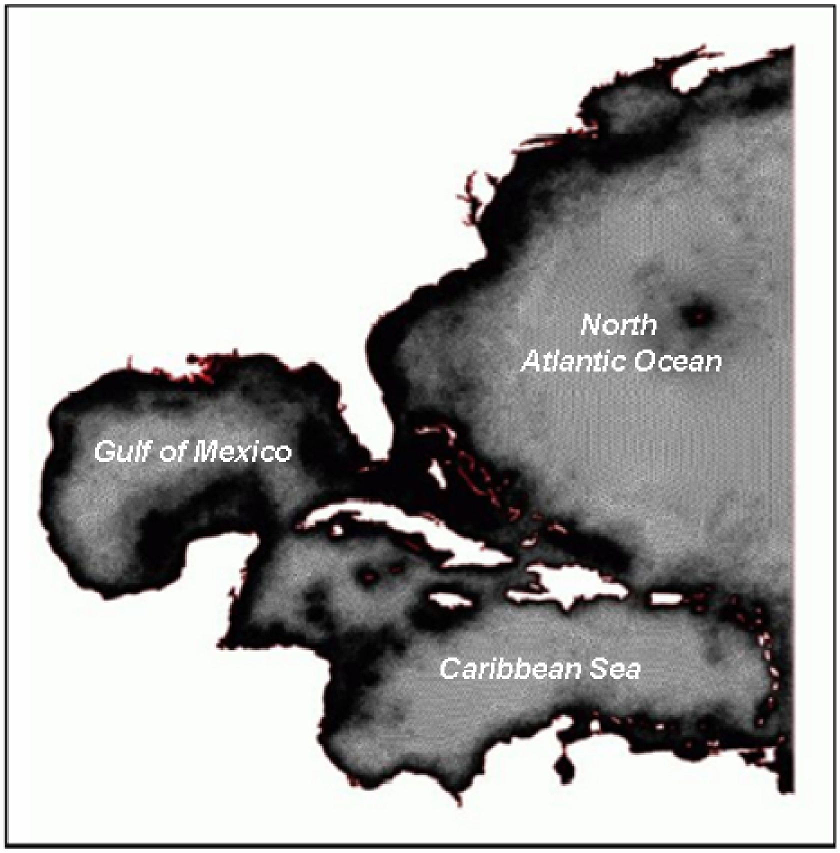


Figure 2-20. The ADCIRC Tidal Database model domain (Mukai et al., 2002).

The largest semidiurnal tides are in the Florida Big Bend and Florida Bay regions with a relative minimum just to the south of Tampa Bay. These spatial distributions were explained by He and Weisberg (2002) based on local geometry. A Lagrangian Stokes drift, coherently directed toward the northwest, was identified but is of relatively small magnitude when compared with the potential for particle transport by seasonal and synoptic-scale wind forcing. Bottom stress-induced tidal mixing was examined and estimates were made of the bottom logarithmic layer height by the M_2 tidal currents. As the tides propagate around the Gulf Basin, they are amplified and slowed as they travel across and along the west Florida shelf. The resulting tides of the inner continental shelf in water depths of 25 m (about 82 ft) or less are of particular importance to the MMS characterization of borrow sites. In shallow water, tides can become relatively large in amplitude and can influence the propagation of surface gravity waves. The currents produced by tides in shallow water at tidal inlets, along the shoreface, and at bay mouth entrances can also erode and transport sand-sized sediments and cause strong wave-current interactions. Figure 2-21 shows a record of water level for early September 2005 at NOS Station 8726724 at Clearwater Beach, FL and Station 8725110 in Naples, FL. These stations bound the MMS study area along the west central Florida Coast and demonstrate the features of the nearshore tides. The plots in Figure 2.21 show the propagation of the tide along the coast from north to south. Thus, there is about a two-hour difference between similar tidal phases at Clearwater Beach and Naples as shown in Figure 2.21. The mean tidal range along the west Florida shoreline in the MMS study area is approximately 0.6 m or about 2 ft. The diurnal range from the lower low tide to higher high tide of the diurnal inequality can reach nearly 1m (3 ft).

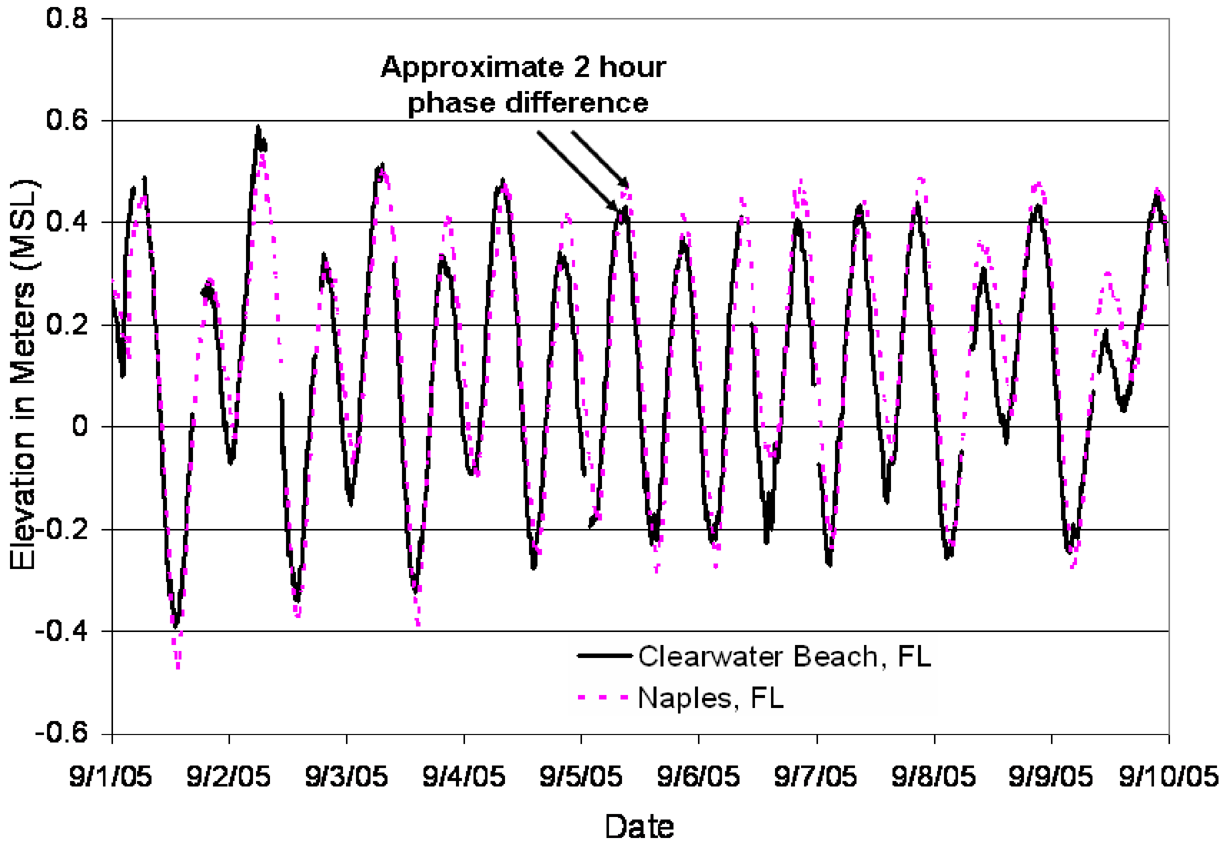


Figure 2-21. Water level records for NOS Stations 8726724 (Clearwater Beach, FL) and 8725110 (Naples, FL). Several gaps are shown in the Clearwater Beach record due to maintenance issues and are noted in the raw data files by a flag (i.e. 999).

The first seven tidal constituents for the Clearwater Beach and Naples coastal stations are summarized in Table 2-1. The M_2 amplitude is less than 0.3 m (about 1 ft) and is very similar at both stations along with the phase of the M_2 tide.

Table 2-1. Comparison of seven (7) tidal constituents calculated from water level records at NOS Stations 8726724 (Clearwater Beach, FL) and 8725110 (Naples, FL).

Tidal	Amplitude in Meters		Phase in Degrees (GMT)	
Constituent	Clearwater Beach	Naples	Clearwater Beach	Naples
M_2	0.246	0.286	123.1	144.2
S_2	0.096	0.096	141.0	156.1
N_2	0.046	0.057	120.3	130.1
K_1	0.158	0.158	12.4	9.9
M_4	0.009	0.017	76.0	123.5
O_1	0.151	0.143	3.6	2.8
Mk_3	0.003	0.009	331.7	322.0

In addition to tidal oscillation, large shifts in sea level occur over a range of subtidal frequencies driven by steric effects, wind patterns and the major current systems of the Gulf. Figure 2-22 is a plot of monthly mean sea level for a 2-year period at the Naples NOS gage to illustrate non-tidal sea level changes. Seasonal changes in sea level are consistent with the analysis of Yang and Weisberg (1999) showing higher sea levels in summer and lower sea levels during the winter months. Changes in sea level recorded at the shoreline as shown in Figure 2-22 are driven by differences in seasonal wind patterns and differences in water temperature (steric effect). In addition, where large current systems exist, changes in the current flux and the related Coriolis Effect can cause changes in seasonal sea levels especially when the constraint of the nearby coast may limit the spin up of compensating flows.

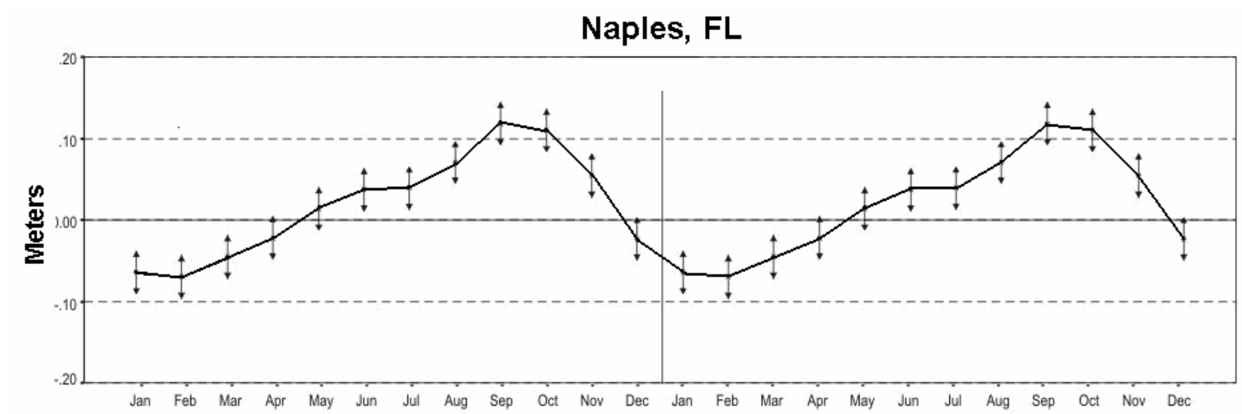


Figure 2-22. Average mean sea level cycle over a 2-year period with 95% confidence intervals for NOAA Water Level Station 8725110 in Naples, FL. Analysis from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS).

2.5.2 Wind-Driven Shelf Circulation

Yang and Weisberg (1999) examined the major wind-driven features of circulation on the west Florida shelf, using the POM (Blumberg and Mellor, 1983). The POM was forced with monthly averaged climatologic winds rather than tidal constituents. The goals of the study were to estimate the seasonal pattern of the west Florida shelf circulation attributable to the climatological wind forcing and to determine whether these patterns can explain the seasonal current reversal found at midshelf. Yang and Weisberg noted that previous Gulf-wide modeling studies did not have adequate resolution to solve the Florida shelf circulation, and provided no evidence of the observed seasonal variations in circulation over the shelf.

The climatology of wind forcing in the Gulf of Mexico includes a pattern of seasonal variation. During the fall and winter months (mid-September to mid-February), winds are primarily from the north. In the late spring and summer (May through mid-August), the northern Gulf of Mexico is dominated by tropical weather with winds mainly from the south. During summer, the influence of the subtropical high (Bermuda High) increases as the frontal zone between subtropical and mid-latitude air masses moves north and out of the Gulf. Weaker pressure gradients and, hence, calmer winds associated with high atmospheric pressure produce less vigorous wind stress forcing of oceanic or, in particular, shelf circulation. During summer, warm fronts generally move from south to north. In order to capture and isolate the effects of these variations Yang and Weisberg (1999) forced the POM using monthly mean wind stress climatology of Hellerman and Rosenstein (1983).

The Yang and Weisberg (1999) study indicated that two seasonal patterns of circulation and sea surface elevation occur under a barotropic setting. A winter pattern occurs from October to March and a summer pattern from April to September. In winter, an anticyclonic gyre over the northeastern (Florida Big Bend) region merges with a northwestward flow from the south. The Big Bend Gyre is caused by a convergence of two separate flows: a nearshore along-shelf southeastward flow and an offshore northwestward flow. The winter circulation characteristics also include offshore surface transport, coastal upwelling, and relatively low coastal sea level. The summer pattern features a continuous northwestward directed flow, onshore surface transport, coastal downwelling, and relatively high coastal sea level. This seasonal pattern can be clearly seen in the long-term sea level from the NOAA CO-OPS stations along the west Florida coast. This trend is apparent from the data shown for NOS Station 8725110 (Naples, FL) in Figure 2-22.

Transitions between the two seasonal patterns show either a development or relaxation of the Big Bend Gyre. These three-dimensional circulation patterns result from wind-driven Ekman transports and their resulting surface-slope-induced geostrophic flows. Yang and Weisberg (1999) demonstrated qualitative agreement between model results and in situ observations, historical drift bottle retrievals, and the tide gage data. The authors also stated that climatological wind stress forcing alone did not account for the seasonally varying southeastward currents observed at midshelf. Thus, they concluded that for depths less than 50 m, seasonal winds may play a dominant role in the seasonal variation of the shelf circulation. At greater depths, a seasonal density related effect is likely to be a factor in the seasonally varying circulation on the west Florida shelf (Yang and Weisberg, 1999). All of the current MMS borrow sites in this characterization study, are located on the inner shelf at water depths less than 50 m, where barotropic response is an important process. Thus, baroclinic flows related to density gradients are likely to be far less important.

2.5.3 The SEACOOS Organization

The Southeast Atlantic Coastal Ocean Observing System (SEACOOS, www.seacoos.org) is a regional partnership that has integrated coastal ocean observing systems for a four-state region (North Carolina, South Carolina, Georgia, and Florida). The long-term intent of SEACOOS is to establish a regional coastal ocean observing system that will be part of the coastal component of the national Integrated Ocean Observing System (IOOS) envisioned by the Ocean U.S. Project. SEACOOS began in September 2002 with funding from the Office of Naval Research (ONR) to coordinate and enhance between several existing subregional-scale efforts in the southeast, Sea Grant Offices from the four states, and a number of federal agencies. The essential elements of the SEACOOS system for the west Florida area are described in this section.

Figure 2-23 shows the observation stations in the west Florida coastal and inner continental shelf area included in SEACOOS. The region-wide observations, overlapping circulation models, data management capabilities, and outreach and education activities of SEACOOS are readily available to the public using links that can be accessed through the main web site. Many of the data and modeling products produced by SEACOOS are available in near real time. The model domain for the west Florida area is based on a POM application (Blumberg and Mellor, 1983). Real time and 84-hour forecasts of shelf currents and

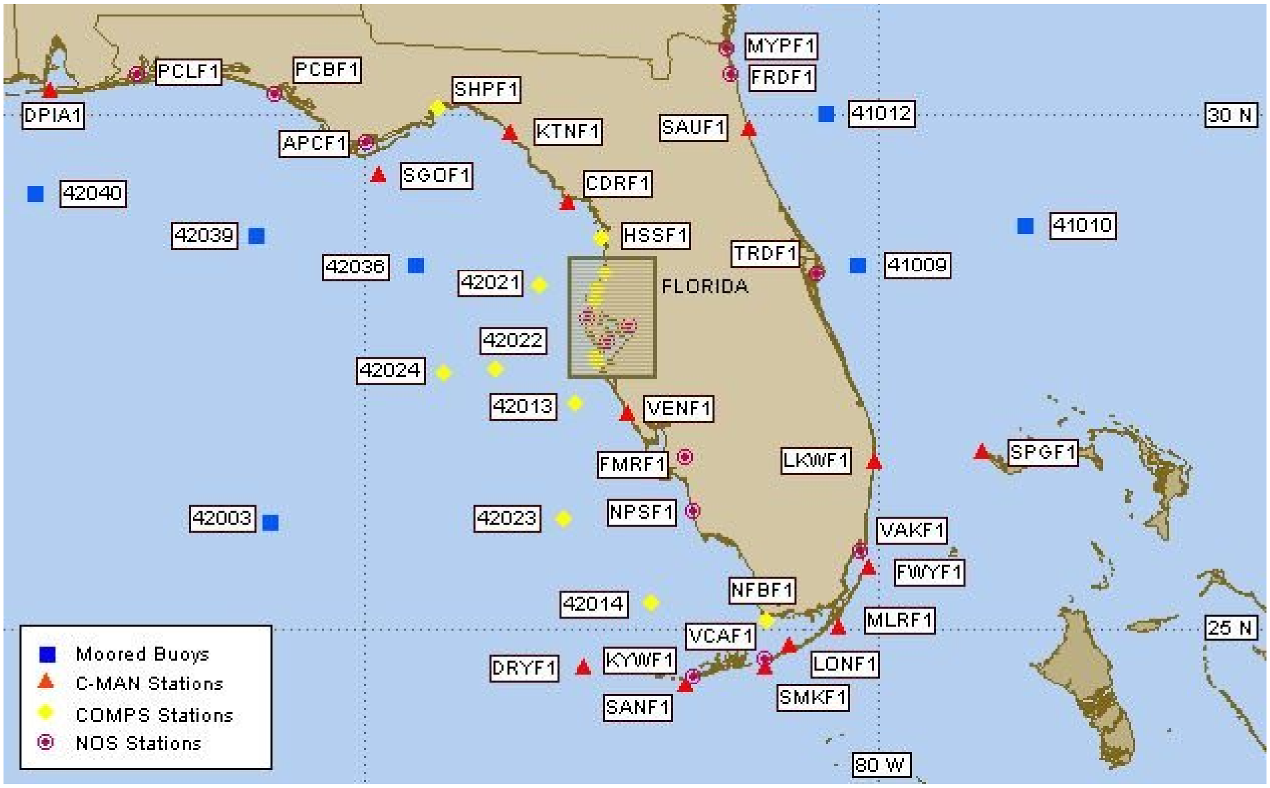


Figure 2-23. Observation stations in the Florida area included in SEACOOS observation network. The west Florida component administered by the University of South Florida is termed the Coastal Ocean Monitoring and Prediction System or COMPS.

water levels can be downloaded in graphic format. The SEACOOS component for west Florida is termed the Coastal Ocean Monitoring and Prediction System or COMPS.

Figure 2-24 shows shelf circulation predicted from the COMPS POM model of the west Florida shelf area for November 2005. The typical southward directed wind-driven flow along the west Florida shelf in the MMS study area is apparent.

2.5.4 Wave Climate, Storms, and Historic Shoreline Changes

The wide and low gradient of the west Florida continental shelf combined with the limited fetch in the Gulf of Mexico results in a relatively mild average wave climate compared to the Atlantic Coast of east central and north Florida. The average breaker height at the shoreline of the west Florida Coast is approximately 1 ft (about 0.3 m) with peak wave periodicity in the 3 to 4 second range. During the passage of frontal systems, breaker heights may reach about 3 feet (about 1 m) with a peak periodicity in the 5 to 6 second range. There are very few long-term observations of the spectral wave field in either shallow or deep water along Florida's west Coast. Thus, incident wave field data from the Wave Information Study (WIS) is the most convenient data source. The WIS data are periodically updated by

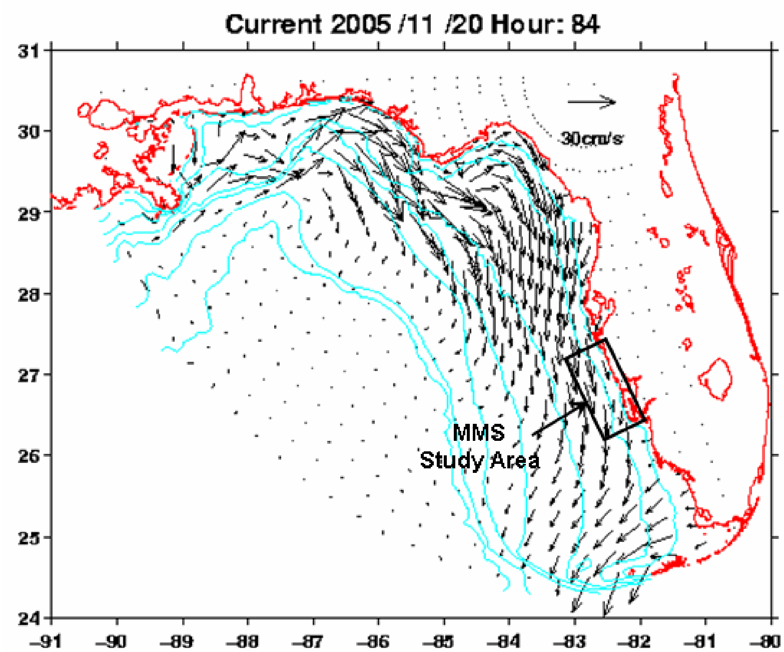


Figure 2-24. The final frame of an 84-hour forecast animation of shelf circulation beginning Nov. 20, 2005 (Prediction from University of South Florida COMPS).

the Coastal Hydraulics Laboratory (CHL) at the U.S. Army Corps of Engineers Waterways Experiment Station (WES) in Vicksburg, MS. WIS hind cast data are generated from numerical models driven by climatological wind fields overlain on grids containing bathymetric data. The WIS numerical hind casts provide long-term wave climate information at nearshore locations (numerical recording stations) of U.S. coastal waters. The spectral water wave characteristic provided at selected numerical wave stations on the west Florida inner continental shelf provided offshore boundary conditions for simulation of wave propagation over the MMS characterization sites. A re-analysis project is currently underway at the CHL to improve the quality of the hind casts using an advanced version of the spectral wave hind cast model WISWAVE. The re-analysis includes more accurate and more highly resolved input winds, and better representation of shallow water topographic effects and sheltering by land forms through use of more highly resolved model domains. Advancements in weather modeling, increased availability of measured wind data (from buoys and satellites), and improved methods for integrating measured data with model-generated wind fields have all contributed to significant improvements in the quality of wind input that is available for use in hind casting. Figure 2-25 shows the approximate position of WIS hind cast station 290 in the Sanibel Island area on the west Florida shelf. Station 290 is one of two WIS stations that will provide hind cast spectral wave data for model simulations. The second WIS station, 272 is located north of Siesta Key.

Station 290 provided spectral wave data to drive simulations of wave propagation over two MMS characterization sites. Figure 2-25 also shows the location of the field monitoring station off Sarasota Beach where nearshore directional wave data were collected during the period of 1993-96. Figure 2-26 shows the joint probability between wave height and peak direction for hind cast wave data at WIS Station 290 between 1995 and 1999. The station is located approximately 18 miles southwest of Sanibel Island where the water depth is approximately 52 ft (16m). Here the joint probability shows relatively low

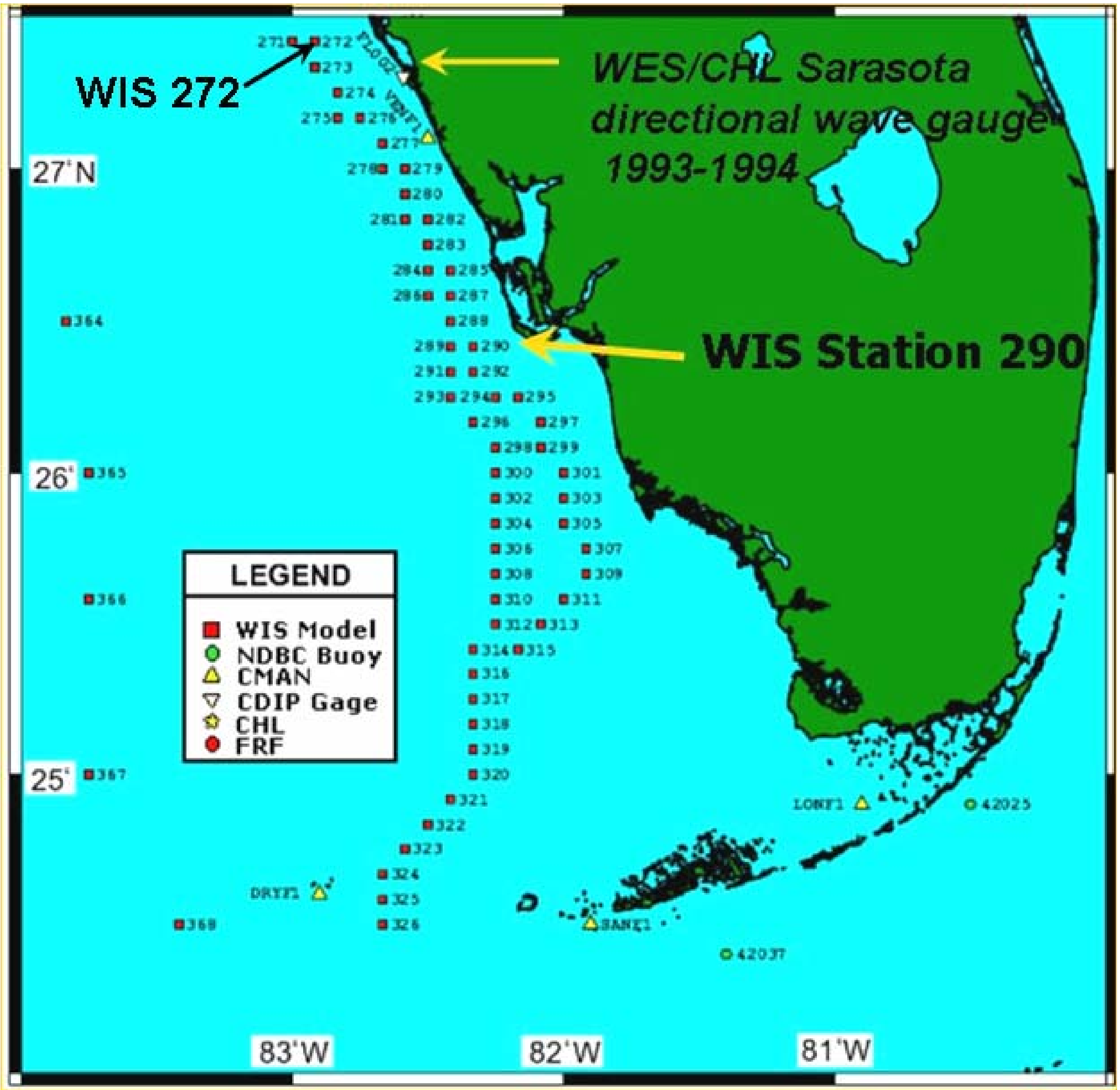


Figure 2-25. Location of WIS Hind cast Stations along the SW Florida Coast.

wave energy arriving from two peak directions, one at approximately 120° and one at approximately 300°. The hind cast data also indicates distinctive seasonal differences in wave energy and direction.

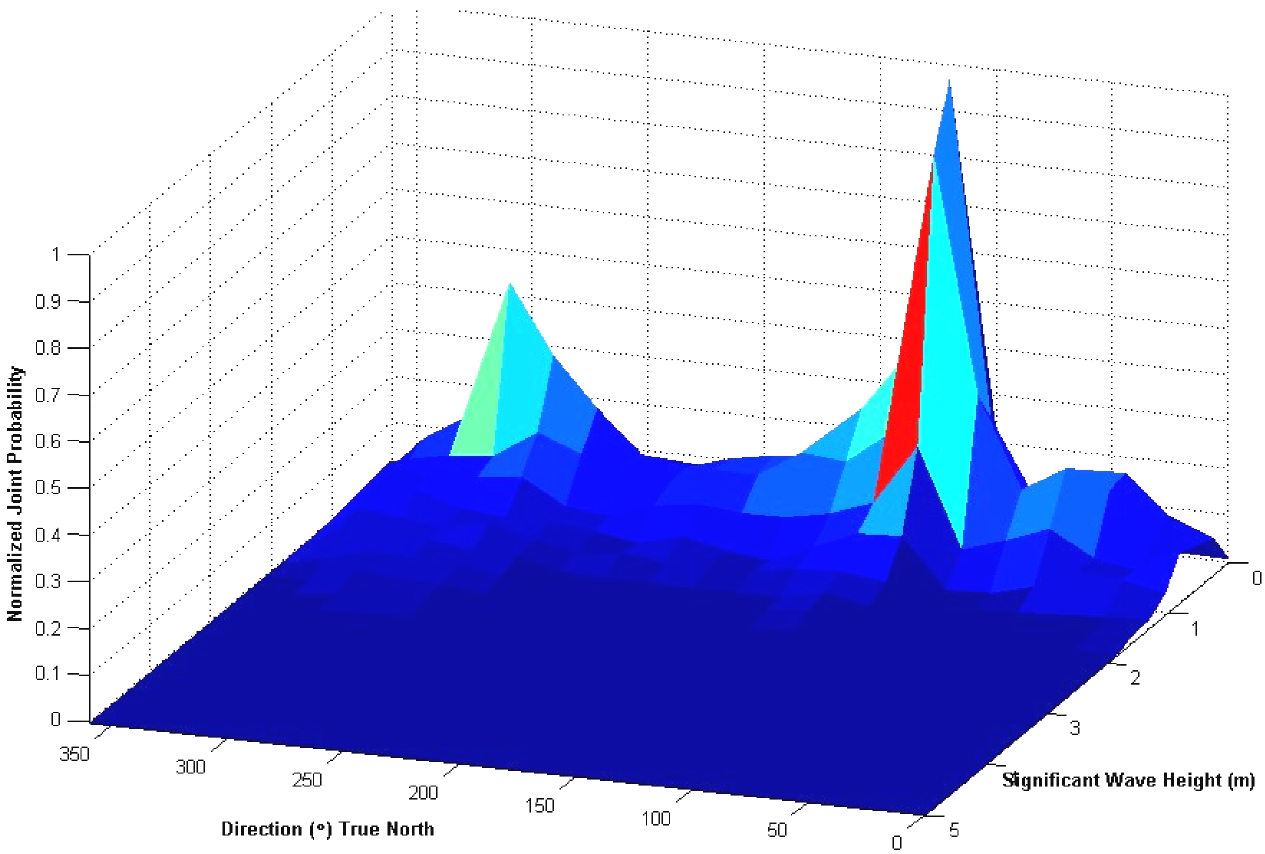


Figure 2-26. Joint probability between significant wave height and peak direction at WIS Station 290. Hind cast time period is 1995-1999.

Figure 2-27 shows the joint probability between direction and wave height at WIS Station 290 between October and April for the 1995-1999 hind cast period. This includes the winter months when there is increased energy from the directional peak centered at about 120^{o} and reduced energy and the occurrence of waves from the northwest direction. To emphasize the seasonal differences in wave energy Figure 2-28 shows the significant wave heights predicted at WIS Station 290, along with a 60-day moving average. The plot shows that average, winter wave height can be in excess of 1 m (3.2 ft), whereas average summer significant wave heights are usually about 0.5m (1.6 ft). Similar patterns of wave energy distribution were found at WIS Station 272 offshore of Siesta Key and Sarasota, FL.

The shallow inner shelf and irregular topography modify waves that approach the shoreline. Thus, nearshore wave spectra can be much different from offshore spectra at the WIS numerical hind cast stations. Figure 2-29 shows the joint probability between measured significant wave height and direction at WES/CHL monitoring station (FL002) deployed in 7m (23 ft) of water between 1993 and 1996. Comparison with the WIS data collected at a depth of 16m (Figure 2-24) shows that the directional spectrum and energy spectrum changes considerably as waves approach the shoreline. Peak direction of wave energy is centered at about 200° and significant wave heights are reduced. Figure 2-30 shows significant wave heights recorded at this station along with a 60-day running average.

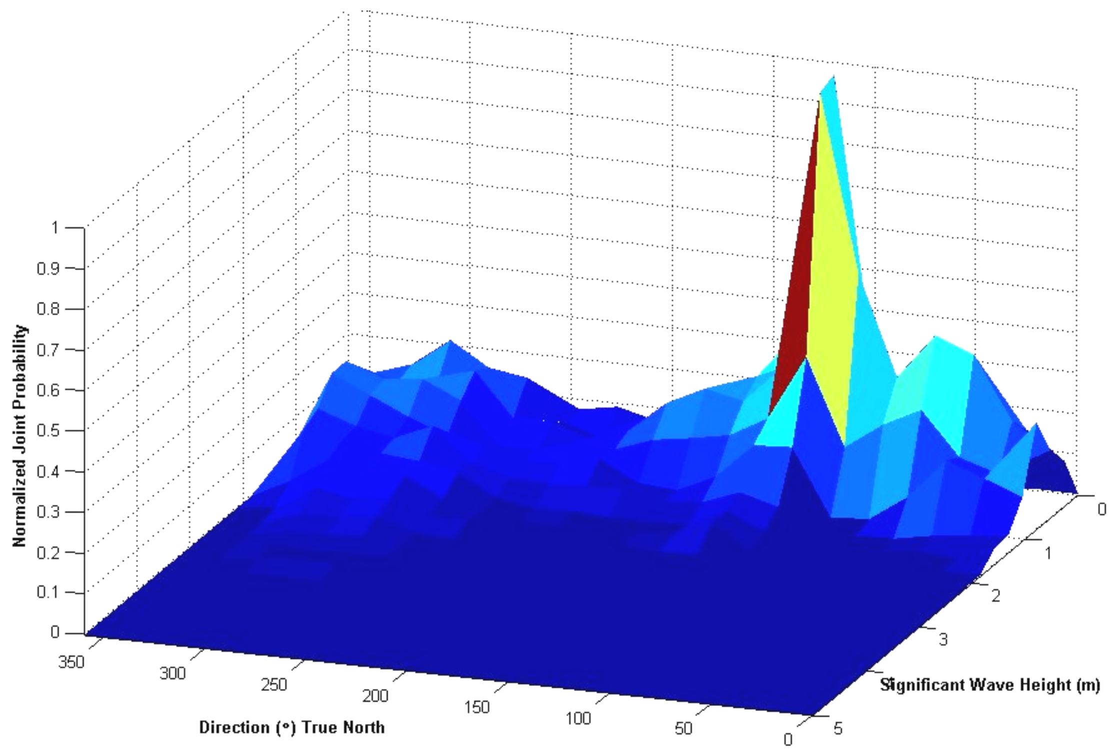


Figure 2-27. Joint probability between significant wave height and peak direction at WIS Station 290 between October and April. The hind cast time period is 1995-1999.

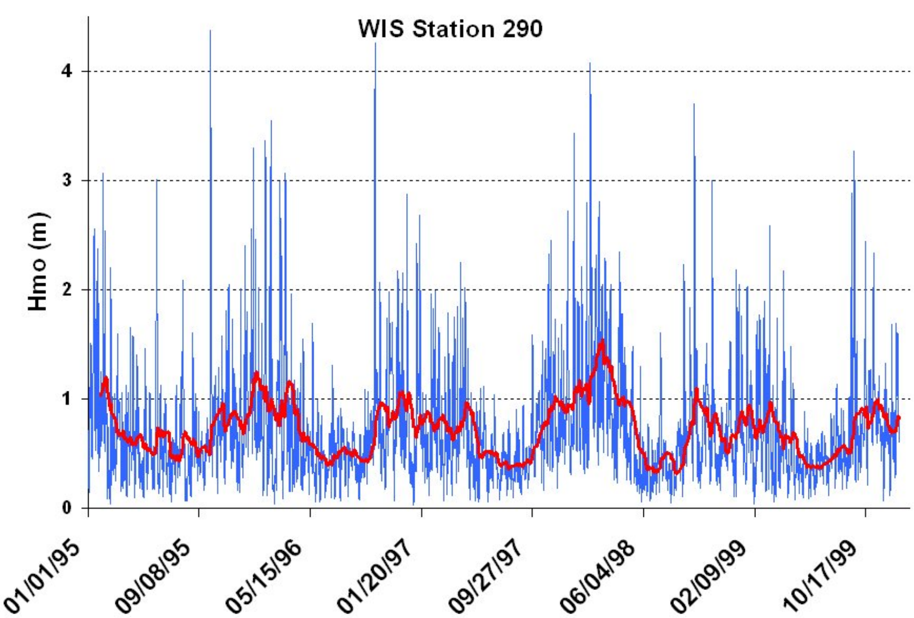


Figure 2-28. Hind cast of significant wave heights at WIS Station 290 from 1995 through 1999. The trend line is a 60-day moving average.

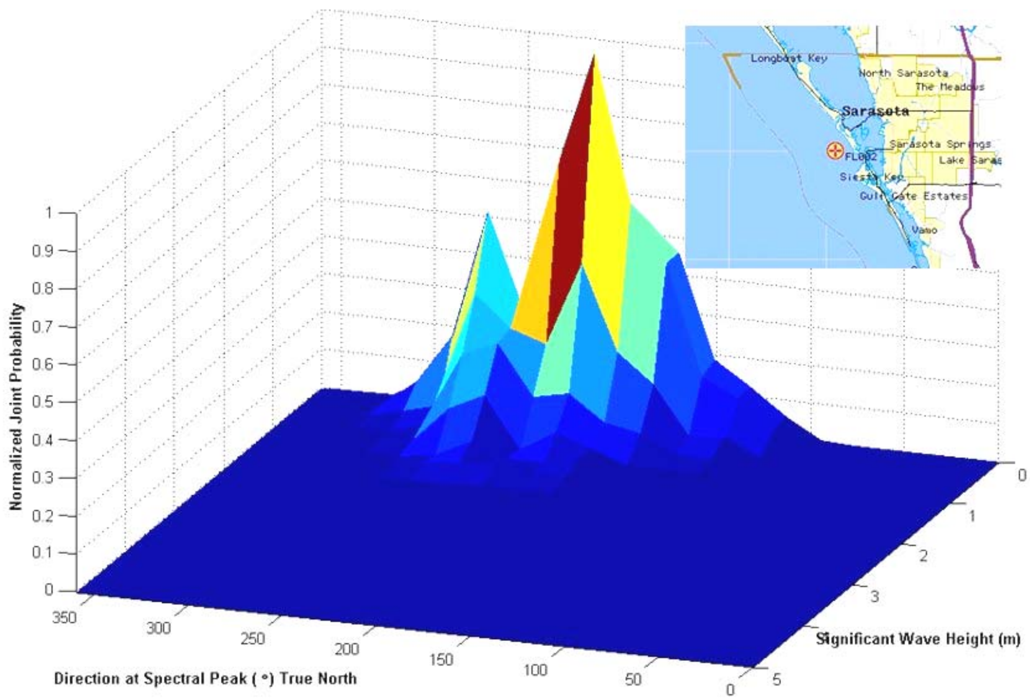


Figure 2-29. Joint probability of significant wave height and peak direction for wave data measured in 7 m of water off Sarasota Beach between 1993 and 1996. Inset shows the approximate location of the directional wave gauge.

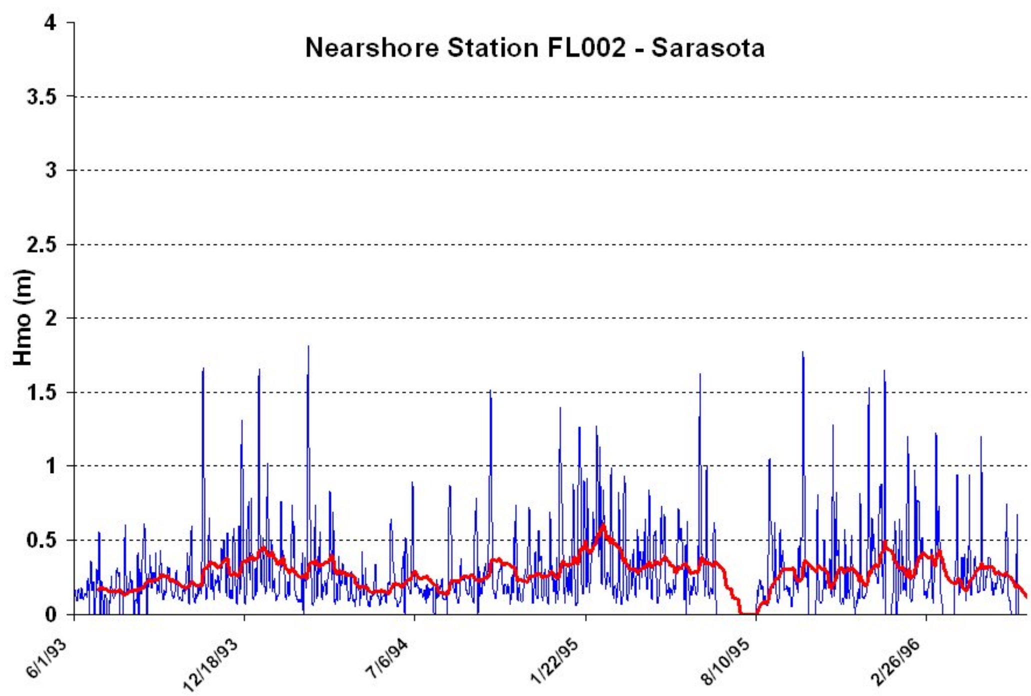


Figure 2-30. Significant wave height record from WES/CHL nearshore directional wave gage FL002 deployed from 1993 to 1996 off Sarasota, FL.

The short period waves approaching the shoreline can arrive at relatively high angles as suggested by Wang et al. (1998). This means that locally strong wave-driven currents can occur in the surfzone, especially during periods of relatively high wave energy. As described by Davis et al. (2003) the primary direction of littoral currents is determined by local shoreline orientation along with the nearshore direction of wave approach. Davis et al. reviewed net littoral transport patterns from field evidence and barrier island and inlet morphology in the central and northern sections of the west Florida barrier island system (Figure 2-31). Davis et al. also reviewed barrier island dynamics of west Florida Coast in view of sediment sources, tidal regime, and wave climate. The similarities between mesotidal or mixed energy inlet and barrier island morphology described by Hayes (1979) and the morphology and dynamics of many of the west Florida barrier islands are described by Davis et al. (2003). Although the tidal regime of west Florida would be termed microtidal on an ocean facing coast, the mild wave climate of west Florida in combination with the relatively large semidiurnal M_2 tide results in some barrier segments having the typical "drumstick" morphology described by Hayes for mesotidal coasts. Davis et al. (2003) described the evolution of barrier islands with respect to local sand budgets, including sand bypassing at inlets pointing out that mesotidal barrier morphology can alter to the more spatially uniform morphology of wave-dominated microtidal barriers. Such transitions can be triggered by storm events that can abruptly alter inlet morphology and eliminate or create local sources of sand.

Davis et al. (2003) presented an historical perspective on the impacts of frontal and tropical storms on the west Florida coast. Figure 2-32 shows historical landfall of hurricanes between 1885 and 1985. Notable historical examples of storm impacts are cited by Davis et al. (2003) including several new inlets and passes opened between 1848 and 1921. More recently, tropical storms of the 1980s and Hurricane Opal in 1996 were mentioned as having significant impacts on morphology and erosion. The impacts of more recent tropical storm systems have been documented by the Florida Department of Environmental Protection (FDEP) as part of the Bureau of Beach and Coastal Systems Program. Leadon et al. (1998) reviewed the impacts of Hurricane Opal in terms of beach and dune erosion and structural damage. A description of the impacts and recommendations for post-storm recovery on the west Florida coast after the 2004 hurricanes can be found in the FDEP web site at http://www.dep.state.fl.us/beaches.

From a coastal engineering and permitting perspective the FDEP Bureau of Beaches and Shores maintains a wide range of data products and reports dealing with shore protection. Much of the data reporting is linked to the FDEP Range Marker system, which is a program for maintaining surveyed bench marks spaced every 1000 feet along the Florida shoreline. Beach profile surveys are conducted intermittently by FDEP survey teams at each marker. In addition, topographic surveys and data collection related to specific shore protection projects are reported within the framework of the Range Marker system. For instance, Figure 2-33 shows the positioning of the Range Markers along Sanibel Island in Lee County. Figure 2-34 shows changes in the mean high water (MHW) shoreline at several of these markers between 1996 and 2002. Other data tied to the markers includes beach profile surveys and volumetric changes over time bounded by the profile surveys.

The FDEP also maintains an on-going analysis of critically eroding shorelines along the Florida coast derived from the database linked to the Range Marker system. Figure 2-35 is an example of a recent update of this information for Lee County, FL.

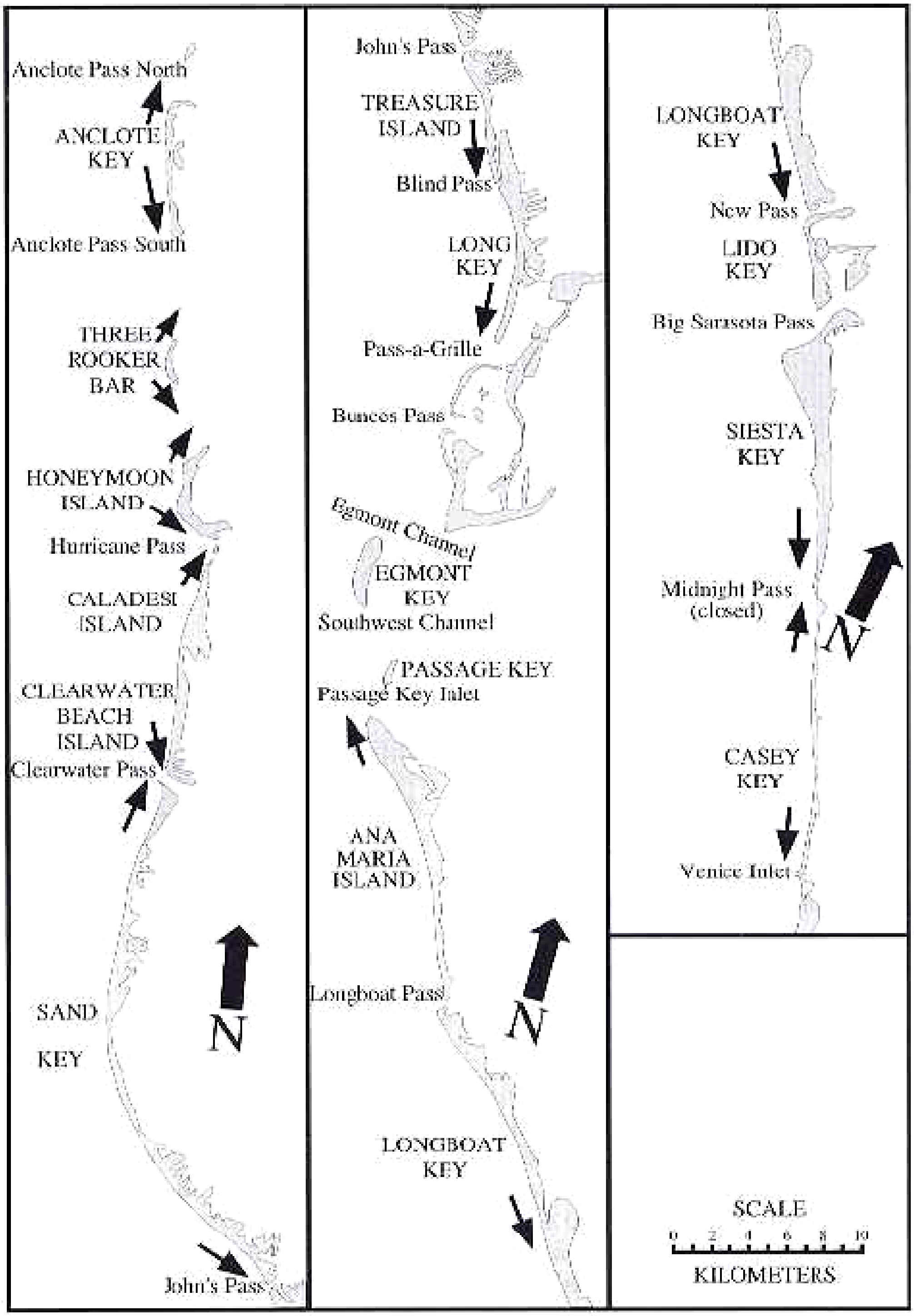


Figure 2-31. Net littoral drift patterns inferred from inlet and barrier morphology by Davis et al. (2003).

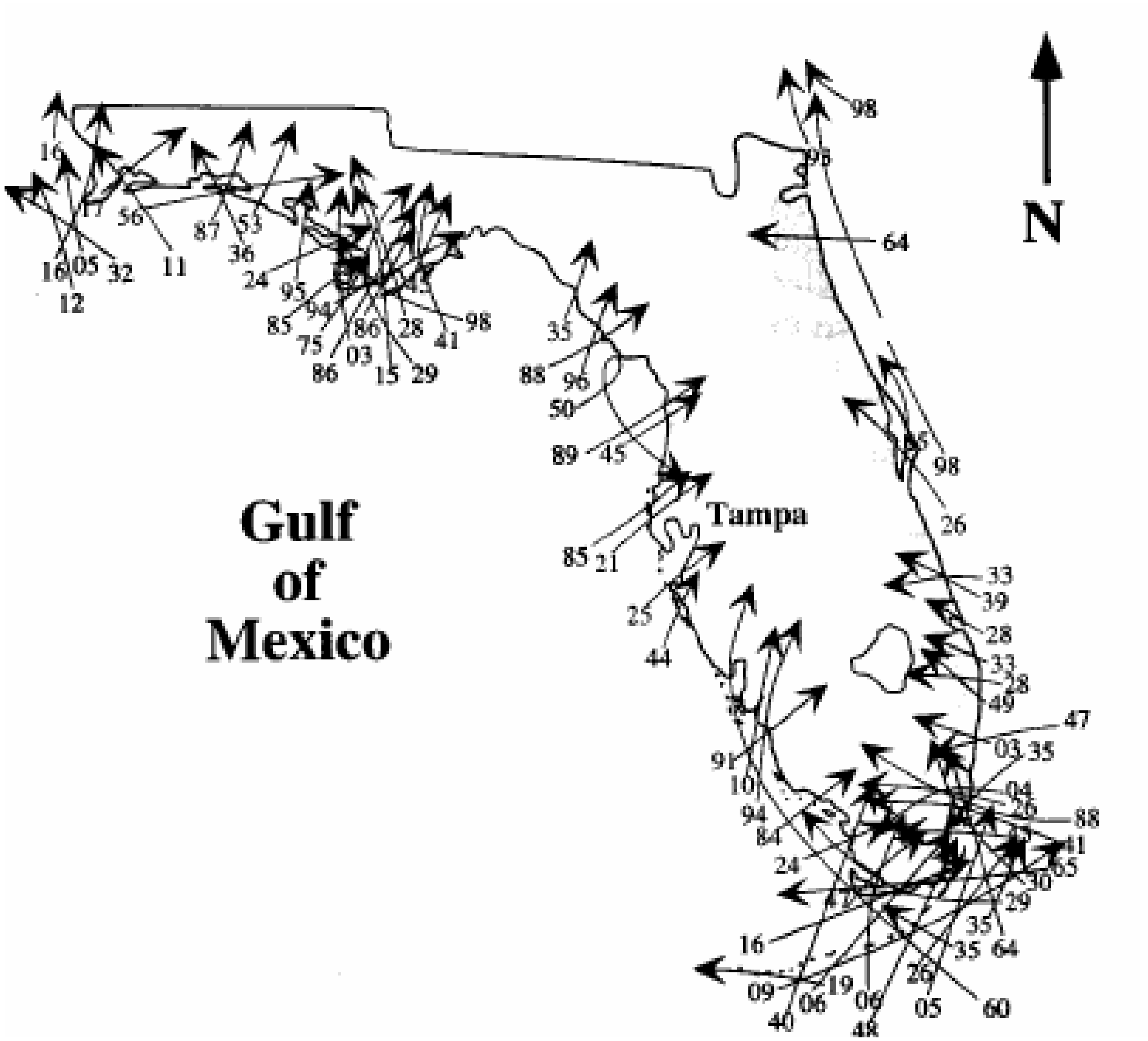


Figure 2-32. Historical landfall of hurricanes on the coast of Florida from 1885 though 1985 (from Davis and Aandronaco, 1987).

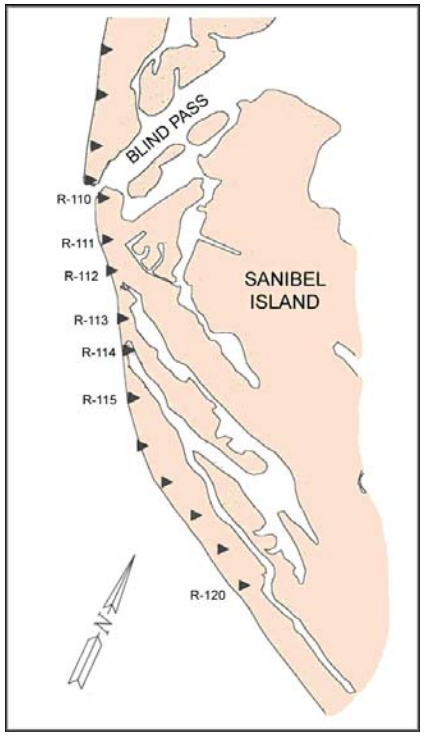


Figure 2-33. Positions of FDEP Range Markers along Sanibel Island in Lee County, FL.

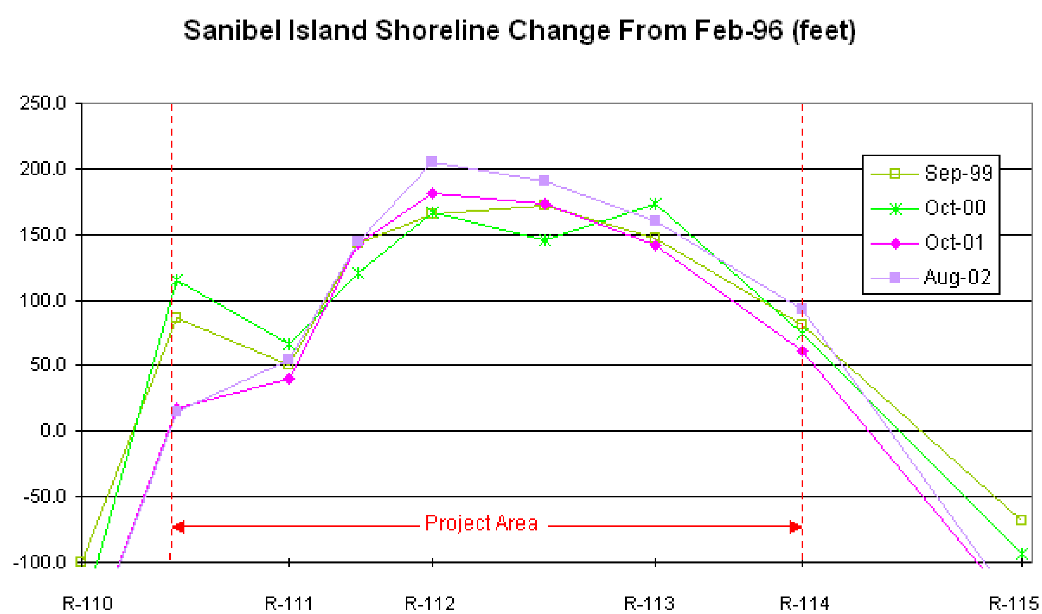
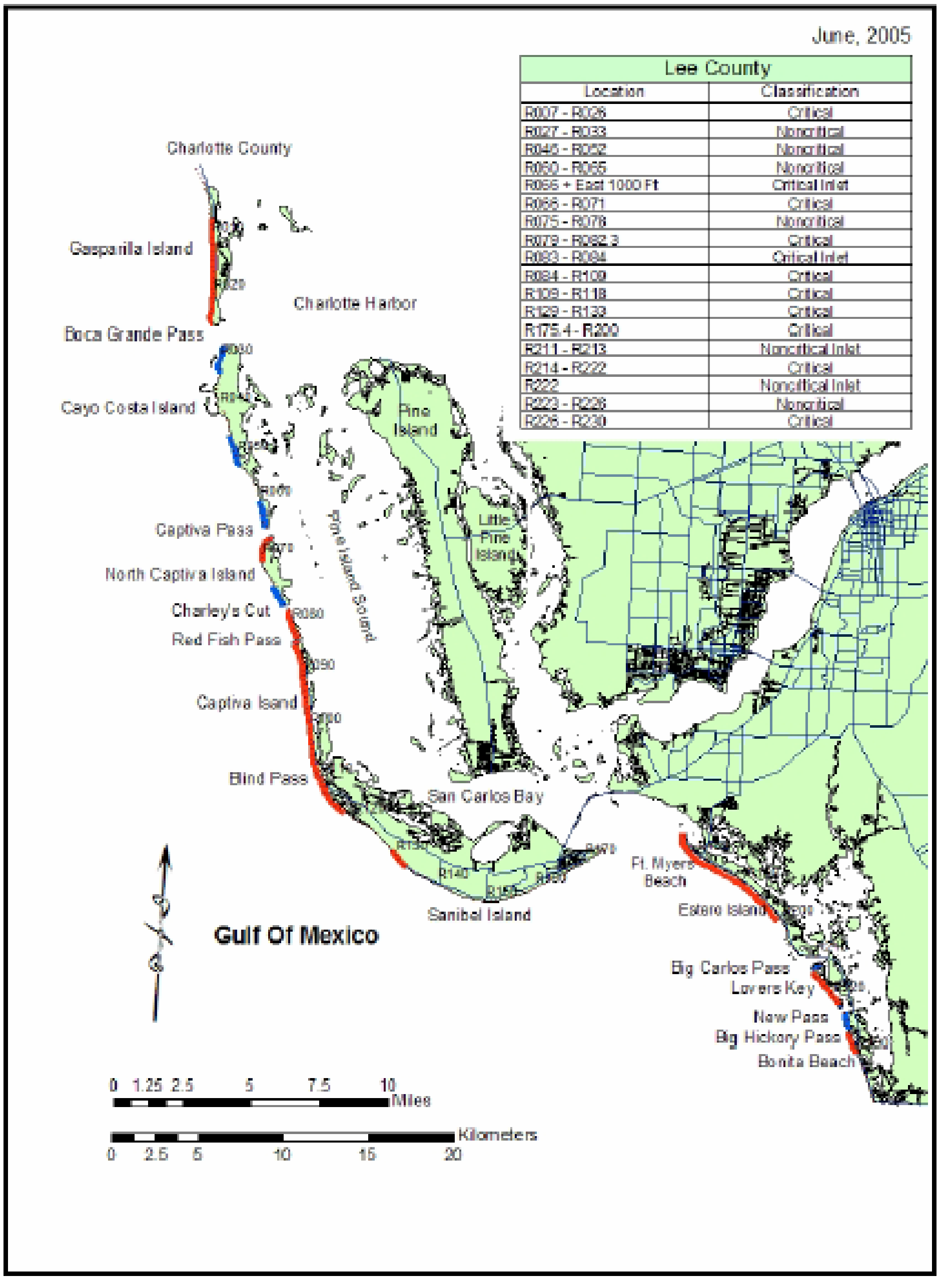


Figure 2-34. Example of shoreline change data compiled from beach profiles available from the FDEP Bureau of Beaches and Shores. Comparison shows shoreline positions relative to the base year of 1996.



Lee County	
Location	Classification
R007 - R026	Critical
R027 - R033	Noncritical
R045 - R052	Noncritical
R060 - R065	Noncritical
R066 + East 1000 Ft	Critical Inlet
R066 - R071	Critical
R075 - R078	Noncritical
R079 - R082.3	Critical
R083 - R084	Critical Inlet
R084 - R109	Critical
R109 - R118	Critical
R129 - R133	Critical
R175.4 - R200	Critical
R211 - R213	Noncritical Inlet
R214 - R222	Critical
R222	Noncritical Inlet
R223 - R226	Noncritical
R226 - R230	Critical

Figure 2-35. Graphic description of eroding and critically eroding beaches in Lee County, FL. Links to the FDEP erosion analysis can be found at http://www.dep.state.fl.us/beaches/.

The FDEP and USGS compiled a long-term analysis of shoreline positions data are provided in a form for convenient display in CAD or GIS software platforms. Both the FDEP and USGS historic shoreline database provide information for the past 150 years. Older shoreline positions were digitized from U.S. Coast and Geodetic Survey (U.S. C&GS) historical maps; whereas shorelines that are more recent were determined from National Ocean Survey (NOS) aerial photographic records and Florida Department of Natural Resources (FDNR) and later FDEP field surveys of beach profiles since the 1970s. The FDEP digital historic shoreline map files are provided in a DWG AutoCAD TM format in the Florida State Plane 1927/79 adjusted horizontal coordinate system. The shorelines approximate the mean high water line.

The USGS database for historical Florida shorelines is part of a larger data set compiled for the entire U.S. Gulf Coast. The details of methodology of the USGS National Assessment of Shoreline Change Project are provided in an USGS Open File Report (Miller et al., 2004). In the USGS shoreline database, the shoreline positions and calculated rates of change were based on merging three historical shorelines with a modern shoreline mapped from LIDAR (light detection and ranging) topographic surveys. Historical shorelines were derived from U.S. C&GS and NOAA historical topographic sheets or T-Sheets, which are the primary data used to compile the U.S. C&GS nautical charts. The periods represented in the USGS project included the 1800s, 1920s-1930s, and 1970s. The most recent shoreline is derived from data collected over the period of 1998-2002 using LIDAR technology. All data were reduced to a mean high water datum and provided to the public as ArcViewTM GIS shape files. Figure 2-36 shows the historical (1885-1895) shoreline positions mapped during the USGS project for the Sanibel Island area. Links to the FDEP AutoCAD TM files can be found at http://www.dep.state.fl.us/beaches/ and links to the USGS Open File Report and ArcViewTM files can be found at http://pubs.usgs.gov/of/2004/1089.

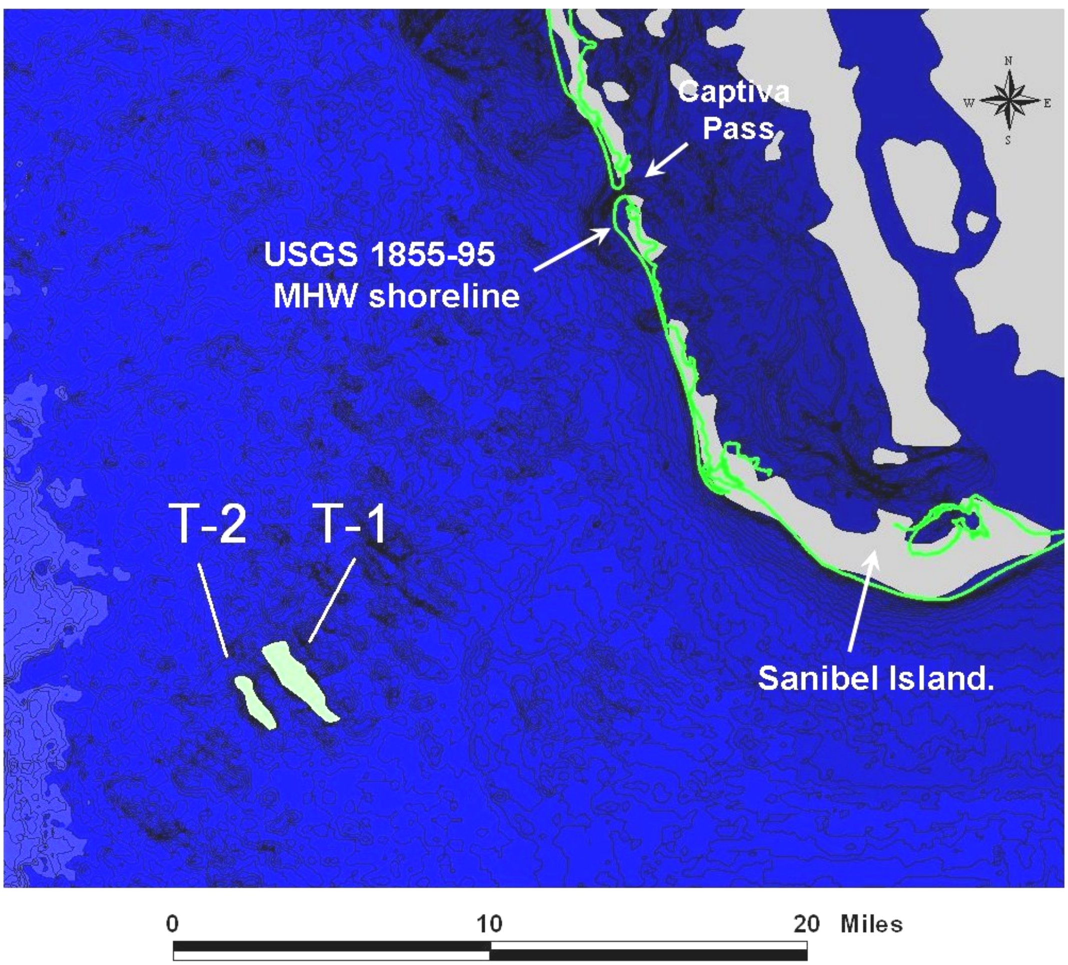


Figure 2-36. USGS mean high water shoreline from 1855 to 1895 in the Sanibel Island area and T1 and T2. ArcViewTM GIS shape files of west Florida shorelines available from the USGS at http://pubs.usgs.gov/of/2004/1089.

2.6 Biological Resources

2.6.1 Benthos

Previous Studies

Several studies have examined the benthos of the west Florida continental shelf (e.g., Florida Department of Natural Resources - Hourglass Cruises various publications including Joyce and Williams, 1969; Camp, 1973; Serafy, 1979; Huff and Cobb, 1979; Myers, 1981; Menzies and Kruczynski, 1983; Dames and Moore, 1979; Woodward-Clyde Consultants and Continental Shelf Associates, Inc., 1983, 1984; Danek and Lewbel, 1986, 1987; Blake et al., 1996; Posey et al., 1998). The studies were conducted in the 1960s through the 1990s using various types of sampling gear. Benthic sampling for the FDNR Hourglass Cruises utilized a box dredge (13 in tall, 36 in wide, 30 in deep) with a 0.75 in x 1.5 in inner mesh. Samples were collected over 28 months (August 1965 – November 1967). Dames and Moore (1979) sampled the benthos using a 0.6 m2 box core and washed the samples through a 0.5 mm screen. Samples were collected 8 times from June 1974 through February 1978. Danek and Lewbel (1986, 1987) reported on a Southwest Florida shelf Benthic Communities Study during which duplicate Smith-McIntyre grabs (0.1 m^2) and triangular dredge (60 cm on each side and 120 cm in length) samples containing a 1.2 cm mesh were collected at each of their stations. Samples were collected in the fall and spring from 1980 to 1985. Blake et al. (1996) utilized a 21.3 cm x 30.5 cm box core to collect samples at four sites between Egmont Key and Venice. Posey et al. (1998) collected 0.01 m^2 cores using SCUBA divers from 12 sites covering 24 km approximately 25 km offshore from Cedar Key Florida (located approximately 200 km north of Siesta Key). Water depths averaged approximately 13 m and sediments were relatively coarse, dominated by fine sands with numerous low relief rock outcrops in the general region.

In addition to benthic sampling, these studies measured physical parameters such as temperature, sediment grain size/composition, and salinity, and addressed benthic spatial and temporal distributional patterns with respect to physical parameters. Figure 2-37 depicts the sampling locations of these previous studies in relation to the three shoal areas sampled in the current study.

Other studies have examined the benthic communities in smaller geographic areas on the western Florida shelf (e.g., Blake et al., 1996). Blake et al. (1996) collected box core (0.6 m^2) samples at four study areas in 5 - 15 m of water depth from Egmont Key to Longboat Key. Samples were collected in July 1992, January 1993, September 1993, and May 1994.

The studies by Dames and Moore (1979), CSA (1985), and Blake et al. (1996) identified bottom habitat types, and benthic infaunal and epifaunal assemblages on the west Florida shelf. The benthic habitats of the nearshore west Florida shelf, within the region of the current study areas, primarily consist of interspersed sand ridges through hard bottom area comprised of limestone bedrock with a thin veneer of sediment. A description of the sedimentary environment of the study areas and region is provided in Sections 2.1 through 2.3.

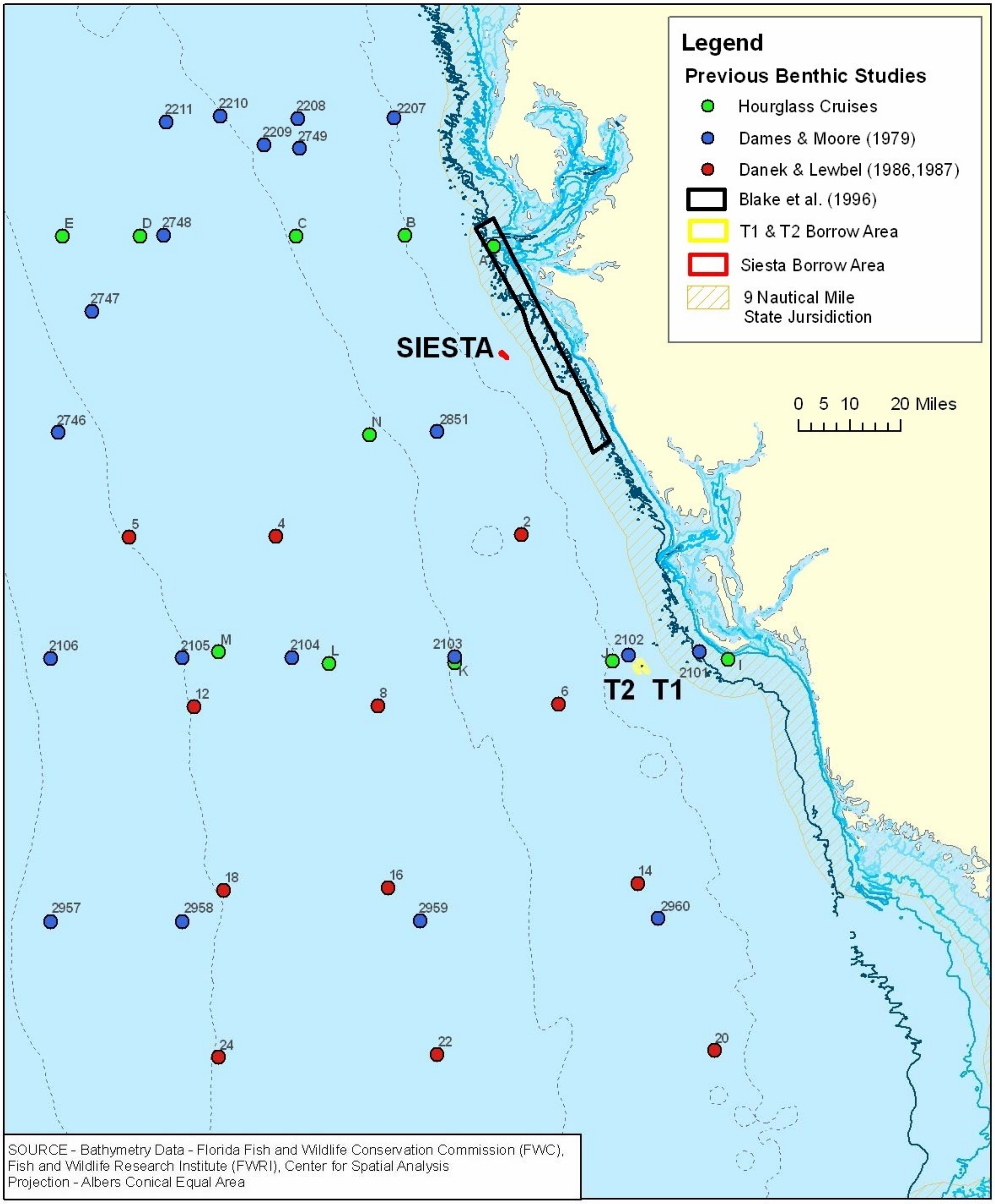


Figure 2-37. Previous benthic grab studies within the west Florida study area.

Overview

Recent studies have concluded that soft-bottom community complexity does not fit a simple paradigm and is not related to a single parameter (Snelgrove and Butman, 1994; Newell et al., 1998). They recommend a shift in approach to understand the relationships of organism distribution patterns in terms of a dynamic relationship between the sediments and their hydrodynamic environment. For example, shear forces at the sediment-water interface play a dominant role in controlling food availability, larval settlement, pore water flow and other parameters that affect benthic organisms (Newell et al., 1998). Environmental factors such as productivity, temperature, and sediment grain size play dominant roles in determining patterns of regional-scale species richness and patterns in species turnover. Seasonality in current patterns, temperature, larval supply, physical disturbances, organic deposition, and many other factors create a mosaic of community development stages on many spatial scales (Renaud et al., 1999). It is likely that the regional scale primarily determines local species richness (Gray, 2002).

Sedimentary characteristics, such as grain size, sorting, and organic content, are important in determining the distribution of benthic communities (e.g., Sanders, 1958; Gray, 1974) in estuaries (Young and Rhoads, 1971), as well as on open continental shelf areas (Dames and Moore, 1979; Weston, 1988; Theroux and Wigley, 1998). However, for the continental shelf benthos, depth also plays a major role in determining benthic community structure (Buchanan et al., 1978; Theroux and Wigley, 1998).

The distribution of sediment grain size plays an important role in determining substrate stability and food availability, which affect benthic community structure and trophic groups present, e.g., suspension – or deposit-feeding taxa (e.g., Rhoads, 1974; Fauchald and Jumars, 1979). Although many infaunal species occur across a range of sediment types, the distribution of many infaunal taxa tend to be correlated to specific sedimentary habitats. Gaston (1987) analyzed the feeding and distribution of the polychaetes of the Middle Atlantic Bight. Surface-deposit feeders numerically dominated most habitats. Subsurface-deposit feeders were proportionately more abundant in fine-sediment habitats. Carnivorous polychaetes were proportionately more abundant in coarser sediments. Sessile polychaetes generally inhabited physically stable habitats.

Hydrodynamic processes also affect benthic community structure (e.g., Eckman, 1983; Hall, 1994). Hydrodynamics affect both macro- and meiofaunal larval transport sedimentary processes, and food resources at several scales (Butman, 1987; Palmer, 1988; Zajac et al., 1998). Storms may affect benthic community composition, especially in shallow versus deep water (Hall, 1994; Posey et al., 1996). Diaz et al. (2004) state that storms are important in structuring benthic communities composition, though individual storm events are unpredictable, their seasonality and frequency have a relatively narrow range over the course of a year. Dobbs and Vozarik (1983) examined the effects of a single storm at a site in 5 m of water and reported no before and after differences in individual densities. They did note that there were many non-reproductive fauna in the water column immediately after the storm. Oliver et al. (1980) examined the effects of wave-induced bottom disturbance on the benthic fauna off the California coast. They noted that in depths of less than 14 m, few organisms lived in permanent tubes or burrows and the abundant fauna were small, mobile, deposit-feeding crustaceans. In deeper water, the community was dominated by polychaetes comprised of taxa that occupied permanent or semi-permanent tubes or burrows. Niedoroda et al. (1989) explored how laminae are laid down in sediment through erosion and redeposition. They concluded that a major storm could deposit a bed several centimeters thick in 20 m of water depth and several millimeters thick in 40 m water depth.

Local bottom topographic features, such as ridges and troughs, also play a role in determining shallow continental shelf macrobenthic communities (Diaz et al., 2004). Diaz et al. (2004) reported that shoal-ridge communities are different from the mid-shoal and trough communities.

Ecological patterns and processes operating at one spatial scale may differ from those at another spatial scale (Whitlatch et al., 1998). Continental shelf soft-bottom benthic community attributes (e.g., diversity, abundance, etc.) vary at small (cm) to regional (km) scales similar to physical parameters (e.g., sediment characteristics, water depth, etc.) (Zajac et al., 1998; Ellingsen, 2001; Diaz et al., 2004). Thus, benthic community response to disturbances varies as the spatial scale of disturbances varies. In addition to spatial scale variations, benthic communities vary on a range of temporal scales such as annual seasonal variations as well as multi-year cycles. Gray and Christie (1983) reported that a number of benthic species show responses to long-term variations in hydrographic conditions (temperature and salinity) ranging from 6 to 7 and 10 to 11 year cycles.

Both temperate and tropical species of benthic invertebrates have been documented within the region of the eastern Gulf of Mexico encompassing the study areas. The Loop Current, and eddies that it releases, intrude on the shelf at irregular intervals and carry larvae from tropical areas (Dames and Moore, 1979). In addition, the benthos of the west Florida shelf exhibit seasonal changes with different patterns occurring among morphological groups. For example, based on studies done during the 1970s of benthic communities off Mississippi, Alabama, and Florida, Dames and Moore reported that polychaete abundance generally declines during the fall and species diversity increases from summer to winter Highest abundance occurs during the summer at shallow sites such as those represented in the current study. In addition, they reported that the maximum number of mollusk individuals generally occurs during the fall with spawning in the spring and summer.

Macro- and meiofaunal benthic communities provide an important food or energy resource for higher trophic levels including demersal fish and large epifaunal organisms. For example, meiofauna are important food sources for fish (Feller and Kaczynski, 1975; Elmgren, 1976; Alheit and Scheibel, 1982). As a result, changes in benthic community structure may result in changes in other trophic levels dependent upon the benthos.

The following terminology is used in subsequent sections of this report. Infauna are organisms that live within the sediment. Epifauna are those organisms that live on the surface of the sediment. Macrofauna are defined herein as those organisms retained on a 0.5 mm sieve (some workers use a 1.0 mm sieve). Typical representatives of the macrofauna include annelids (polychaetes and oligochaetes) and crustaceans (decapods, panaeids, amphipods, isopods, tanaids, and cumaceans). Meiofauna are defined herein as those organisms passing thru a 0.5 mm sieve but retained on a 0.063 mm sieve. Typical representatives of the meiofauna include harpacticoid copepods, nematodes, turbellarians, kinorynchs, and gastrotrichs. Newly settled macrofauna may be contained in the meiofauna component of the benthos.

The unvegetated sand shoals/ridges are the focus of the current study and the benthic communities associated with these areas are described in detail below.

Benthic Macrofauna

Infauna

The predominant infaunal macroinvertebrates inhabiting sand bottom habitats of the inner shelf of the nearshore west Florida shelf include polychaetes, crustaceans, echinoderms, and molluscs. Infaunal assemblages that inhabit this area include taxa common to most of the eastern Gulf of Mexico (Dames and Moore, 1979; Lyons 1979; CSA, 1985; Danek and Lewbel, 1986) and tropical areas of southern Florida and the Caribbean (Foster, 1971; Camp et al., 1998). Inner shelf infaunal assemblages of sand bottom habitats in the study area are numerically dominated by polychaetes in terms of overall abundance and taxa (Danek and Lewbel, 1985; Blake et al., 1996). Amphipods and bivalves are also well represented in the inner shelf infaunal community. Infaunal assemblages that inhabit the study area are similar to those of sand bottom habitats of other regions in that they exhibit spatial and seasonal variability in their distributions.

A total of 620 infaunal taxa were identified in shallow (depths 5 – 15 m), sandy habitat off southwest Florida by Blake et al. (1996). Annelids contributed 44% and 49% of the taxa and individuals, respectively. Molluscan fauna represented 22% of the taxa and 29% of the total fauna, while crustaceans comprised 27% of the taxa and 11% of the individuals. These three taxonomic groups represented 93% of the taxa and 89% of the total fauna.

Danek and Lewbel (1986, 1987) conducted benthic infaunal surveys at five sandy bottom stations at depths ranging from 11 to 18 m, south of Charlotte Harbor. They identified 414 taxa. Polychaetes were the most numerous and represented 223 of the total taxa. Crustaceans were the second most numerous with 117 taxa, 52 of which were gammarid amphipods. Molluscs were represented by 54 taxa, with 23 gastropods, 25 bivalves, 5 scaphopods, and 1 polyplacophoran. Echinoderms were represented by 7 taxa. The remaining 13 taxa were *Phoronis architecta*, *Glottidia pyramidata*, *Branchiostoma caribaeum*, oligochaetes, bryozoa, sipunculids, priapulids, pycnogonids, turbellarians, rhynchocoels, demospongiae, and hydrozoa. Estimated mean densities were higher in May than in December at four of the five stations.

Dames and Moore (1979) surveyed benthic infaunal communities on the continental shelf along the eastern Gulf of Mexico, as part of the MAFLA program. Macroinfaunal mollusc, polychaete, and crustacean communities were sampled with a box corer. Two stations were located inshore of the 20m isobath on the southwest Florida shelf, off Charlotte Harbor. Of the more than 30 mollusc species found at these stations, the community was dominated by *Parvilucina multilineata*, *Tellina versicolor*, and *Varicorbula operculata*.

Eighty polychaete species were identified from stations outside Charlotte Harbor during the MAFLA program (Dames and Moore 1979). The polychaete assemblage at these stations was dominated by *Exogone dispar*, *Aglaophamus verrilli*, *Nephtys picta*, *Lumbrineris cruzensis*, *Prionospio fallax*, *Aricidea taylori*, *Mediomastus californiensis*, and *Owenia fusiformis*.

Dames and Moore (1979) reported that polychaete species abundance and richness in the eastern Gulf of Mexico exhibit seasonal patterns suggesting that temporal changes in hydrography and substrate play an important role in benthic community structure. They reported heavy recruitment of polychaetes during early summer, which results in high abundances, while individual and species abundance decrease during the winter. They speculated that causes for mortality of some species might include storm activity or decreased temperature.

Using the FDNR Hourglass cruise data, Lyons (1979) reported on the Muricidae molluscan communities of the west Florida shelf. Muricids are gastropods with over 25 species occurring within the west Florida shelf region. The current study areas fall within the area designated by Lyons as "Shallow Shelf" (10 – 30 m). The most common Muricid species collected included apple murex (*Chicoreus pomum*), pitted dwarf murex (*Favartia cellulose*), lace murex (*Chicoreus dilectus*), *Murexiella glypta*, and hexagonal murex (*Muricopsis oxytatus*).

Posey et al. (1998) conducted a 3-year study of the infaunal communities off Cedar Key, Florida in approximately 13 m of water. They reported 472 taxa collected for the entire 3-year study. Polychaetes dominated the community with 203 species, followed by amphipods (57 species), bivalves (52 species, though most represented by only juveniles), and gastropods (36 species) representing most other fauna sampled. Common polychaete species included; *Glycera* sp., *Prionospio cristata*, *Prionospio fallax*, *Synelmis* sp. B, *Armandia maculata*, *Cirrophorus forticirratus*, *Aricidea* (*Acmira*) sp. D, *Spiophanes bombyx*, and *Paraonis pygoenigmatica*. The cephalochordate *Branchiostoma caribaeum* was also a common representative of the benthos.

There was a general trend towards some taxa being numerically dominant and others representing a consistent subdominant assemblage. There was also variation in the relative numbers of many common organisms. Some of this variation appeared to follow seasonal patterns, as reflected in seasonal variations in relative numbers of certain functional groups. In particular, deposit feeders became numerically more important during winter and suspension feeders increased in importance during summer. Suspension feeders in this study were dominated by juvenile clams and *Branchiostoma*. Most clams observed were relatively small, probably less than 1 year in age, suggesting a settlement dominated system with high post-recruitment mortality. Higher numbers of suspension feeders in summer may reflect recent recruitment while winter lows may reflect mortality over the previous year.

Brooks et al. (2004) summarized eighteen surveys in the Gulf of Mexico and reported that spring and/or summer were peak seasons for spawning, abundance, biomass, and diversity values for the benthic assemblages. In addition, the majority of Gulf of Mexico studies reported a lack of any strong relationship between sediment grain size and macrofaunal abundance, density, or community structure.

Epifauna

CSA (1985, 1987) identified hard and soft bottom epifauna assemblages off southwest Florida, and found sparse epifaunal assemblages in the highly dynamic sand habitat. CSA (1985) mapped and described several biological assemblages including an Inner and Middle Shelf Sand Bottom Assemblage and an Inner Shelf Live Bottom Assemblage I. The Inner and Middle Shelf Sand Bottom Assemblage was predominant on sand bottom substrates with an attached macroepifaunal density of less than approximately one individual per m^2. Associated biota consisted of algae (*Caulerpa* spp., *Halimeda* spp., *Udotea* spp., and coralline algae), asteroids (*Astropecten* spp., *Goniaster tessellates*, *Luidia* spp., *Narcissia trigonaria*, and *Oreaster reticulates*), bryozoans (*Celleporaria* spp., and *Stylopoma spongites*), hard corals (*Scolymia lacera*), echinoids (*Clypcaster* spp., *Diadema antillarum*, and *Lytechinus* spp.), holothuroids, sea pens, and sponges (*Geodia gibberosa*). Algae covered up to 75% of the seafloor in some photographs, whereas epifauna were found in widely scattered patches. The sponges and solitary hard corals may have been attached to a hard substrate, but their occurrence was limited in this assemblage. Sand waves, ripple marks, and evidence of bioturbation were sometimes present. This assemblage was found in depths of 10 to 90 m, and was interspersed with the Inner Shelf Live Bottom Assemblage I at depths inshore of the 20 m isobath. This live bottom assemblage found at depths of 10 to 27 m consisted of patches of various algae (*Caulerpa* spp., *Halimeda* spp, and *Udotea* spp.), ascidians, hard corals (*Siderastrea* spp.), large gorgonians (*Eunicea* spp., *Muricea* spp., *Pseudoplexaura* spp., and *Pseudopterogorgia* spp.), hydrozoans, and sponges (*Geodia gibberosa*, *Haliconia* spp., *Ircinia campana*, and *Spheciospongia vesparium*).

Blake et al. (1996) examined infaunal and epifauna communities on the sand bottom ranging from 5 to 6 m depth, at four sites off southwest Florida, from Tampa to Fort Meyers. Epifauna fauna were surveyed through video transects and by otter trawl. Observations of flora and fauna during the video transects were rare, reflecting the low epifauna diversity of this highly mobile bottom type. The crab, *Portunus gibbesii*, and the sand dollar, *Mellita tenuis* were by far the most dominant epifauna species caught with otter trawls, with the shrimp, *Penaeus duorarum*, a distant third.

During the FDNR Hourglass Cruises, epifauna sampling was conducted at ten stations on the southwest Florida shelf, at depths ranging from 6 to 73 m using a box dredge. This study identified 32 species of marine isopods, 25 echinoid species, 5 scyllarid lobster species, and 13 species of aorid amphipods in this area (Lyons, 1970; Serafy, 1979; Myers, 1981; Menzies and Kruczynski, 1983).

Benthic Meiofauna

The meiofauna of the west Florida shelf region is not well described. Ivester reported on meiofauna in the Dames and Moore (1979) MAFLA study. In this study meiofauna were comprised of nematodes (70.3%), harpacticoids (14.2%), and polychaetes (4.5%). Association patterns between taxa, between and within stations, and between seasons did not reveal any definitive trends (Dames and Moore, 1979). Correlations between taxa and physical parameters were non-existent or weak (Dames and Moore 1979). In subtidal habitats, the majority (approx. 90%) of meiofauna are present in the top 5 cm. The total meiofauna densities ranged from 65 – 3,752 per cm^2. Meiofaunal densities were highest in water less than 40 m deep. No seasonal reproductive patterns were discerned and density peaks did not coincide from year to year.

2.6.2 Fishes

The west Florida shelf possesses a diverse ichthyofauna and supports economically valuable commercial and recreational fisheries. Although life history strategies vary greatly across species, the majority of Florida OCS fishes are teleost (bony) taxa that produce large numbers of small pelagic eggs and/or larvae that can disperse widely in coastal waters. Larvae of many common coastal teleosts employ both passive and active means to recruit to specific habitat types such as estuarine marshes, seagrass beds, or shallow nearshore reefs. Elasmobranch fishes (sharks, rays, and skates) of the Florida OCS differ in that they produce fewer, well, developed young but may also utilize discrete nurseries. With age, habitat associations of coastal fishes can change with many taxa undertaking obligate migrations to deeper marine waters, often for spawning purposes.

Given the of planktonic dispersal ability of eggs and larve and/or the mobility of most adult Florida OCS fishes, the ichthyofaunal assemblage throughout the southwest is variable and depends on the spatial distribution of bottom substrates as well as season, water depth, hydrological conditions, and biological productivity along the coast. A review of existing data on species and habitats known from the area provide an appropriate starting point when evaluating the fish fauna expected to occur in the vicinity of offshore sand shoals of southwest Florida. Data for this review are derived from several sources including published peer-reviewed faunal surveys and species-specific investigations, program reports generated by various government agencies, and landings data obtained from regional recreational and commercial fisheries.

Previous Studies

Although there are numerous studies addressing the biology and ecology of individual fish species that inhabit Florida coastal waters, there are few broad faunal surveys characterizing spatio-temporal patterns in abundance and community composition along the west Florida shelf are limited. Smith (1976) conducted an extensive visual survey of known hard bottom features 11-51 km west of Sarasota and documented rocky outcroppings covered by diverse assemblages of algae, soft and hard corals, sponges, and other sessile invertebrates. A total of 101 fish species from 38 families were observed on these patchy outcrops including groupers, snappers, and other typical Florida reef associates. The most comprehensive coastal ichthyofaunal survey to date was an intense trawling program conducted by Pierce and Mahmoudi (2001) each April from 1994 to 1997 on the west coast of peninsular Florida (26ºN to 29ºN). They captured 111 fish taxa from 38 families from depths between 6 and 27 m. Offshore substrates, characterized by open sand with interspersed patches of hard-bottom, supported a variety of reef and forage fish species including groupers, snappers, grunts, porgies, as well as, small pelagic species such as round scad and Spanish sardines. Nearshore substrates were generally uniform sandy bottoms that supported smaller fish species such as demersal pinfish, mojarras, and porgies, and contained abundant pelagic schooling species, including Spanish and scaled sardines, thread herring, and Atlantic bumper.

Estuarine fish surveys are also important for characterizing the west Florida shelf ichthyofauna, especially in nearshore coastal areas. The Florida Fish and Wildlife Research Institute (FWRI), a research arm of the Florida Fish and Wildlife Conservation Commission (FFWCC), conducts an intensive fisheries-independent monitoring effort of fish faunas inhabiting large Florida estuaries including Charlotte Harbor and Tampa Bay. Poulakis et al. (2004) used FWRI data as well as museum collections and other published records to identify 255 fish species from 95 families found within Charlotte Harbor. Some of these taxa are considered fulltime estuarine residents, but many are transients that utilize estuaries as juvenile nurseries and undertake obligate migrations to shelf waters as they mature, possibly to discrete spawning sites. These transient taxa may also be vulnerable to dredging disturbance at sand resource areas during certain times of the year.

Fisheries landings data provide a mechanism for identifying fish species, which if perturbed by sand dredging or other human activities, may cause economic harm to west Florida coastal communities. The fisheries data included here were derived from two sources. Commercial landings data obtained by the FWRI are available for all Florida coastal counties and include total poundage of each species landed annually as well as the number of fishing trips made to acquire those landings. For this report, the most recent set of commercial landing data (2005) were compiled from coastal counties nearest to sand borrow sites currently under study: Lee, Charlotte, Sarasota, Manatee, Pinellas and Hillsborough Counties. Recreational fisheries landings are jointly monitored by the FWRI and the National Marine Fisheries Service (NMFS). Queries of the Marine Recreational Fishery Statistics Survey (MRFSS) database at http://www.st.nmfs.gov/st1/recreational/index.html provided estimates of the total number of individuals landed for each species taken in the recreational fishery during 2005. The smallest geographic region available in the database is "West Florida" so these data do not provide precise capture locations, but as with commercial landings, will help identify important species present in the region. The 2005 commercial and recreational fish and shellfish landings for the study area are in Appendix A.

The combined commercial and recreational landings data for the southwest Florida coastline contain 75 individual fish taxa and 22 mixed-species categories (e.g., flounders, baitfish, and mixed grouper). The dominant commercial finfish species, in terms of pounds landed in the coastal counties of interest, are striped mullet, red grouper, thread herring, ladyfish, and gag grouper. Recreational catches are numerically dominated by spotted seatrout, gray snapper, various grunts, gag grouper, and Spanish mackerel. Pinfish are also recorded as a large component of the recreational fishery but this small-bodied species is utilized almost exclusively as bait. Invertebrates also sustain important commercial and recreational fisheries with landings dominated by pink shrimp, blue crabs, stone crab, rock shrimp, and sponges.

Information on the biology and ecology of the dominant fishery species of the region was reviewed to determine the life stages of species that may be most severely impacted by offshore sand dredging. Habitats utilized by the different life stages for important fishery species are summarized in Table 2-2 and their spawning seasons are listed in Table 2-3. The review also included taxa supporting valuable fisheries not recorded in landings data such as snook, a prized recreational species caught along the southern coastlines of Florida, and tarpon, which supports a large catch-and-release fishery. Life histories of species that do not support a significant fishery yet fill important ecological roles in the coastal ecosystem as prey for larger fishes and as predators on benthic fauna are discussed.

Pelagic Fishery Species

Pelagic marine fishes spend their entire lives in the water column of estuarine, coastal, and offshore habitats. Many small-bodied pelagic species (e.g., herrings, mullets), form large migratory schools that serve as important forage for larger fishes, marine mammals, and sea birds. Larger pelagic taxa generally are important predators of fish and cephalopods and may travel singly (e.g., cobia, tripletail) or in large schools (e.g., mackerels, tunas). Some pelagic species are the target of intense commercial and recreational fisheries. Dominant pelagic fishery species along the coast of west central Florida include:

Striped Mullet (*Mugil cephalus*) – Adult striped mullet reside both in estuaries and nearshore coastal waters but migrate offshore to spawn along the outer continental shelf from November to January (FWRI, 2005). Small juveniles feed on zooplankton as they migrate back across the shelf and into estuarine nurseries during spring. As they mature, their diet shifts to detritus and epiphytes.

Striped mullet were the target of nearly 25% of all commercial fishing trips throughout the region in 2005 with landings exceeding 3.7 million pounds. The commercial fishery focuses on estuarine adult and juvenile populations, primarily in Pinellas, Charlotte, and Manatee Counties. Landings, which decreased dramatically in 1995 following the passage of a ban on the use of inshore gill nets, have rebounded as the fishery has since been reestablished using different gear types (FWRI, 2005). Mullet are typically marketed as bait, highlighting their importance as prey for many predatory fishes.

Atlantic Thread Herring (*Opisthonema oglinum*) – Thread herring are schooling planktivorous fishes that support a valuable coastal purse seine and cast net fishery. Almost the entire regional catch of 1.5 million pounds in 2005 was landed in Manatee and Pinellas Counties. These small pelagic fish undertake seasonal migrations through Florida's nearshore waters and estuaries. They have been reported to spawn from March to July in shelf waters in depths of 100 ft or less (FWRI, 2005). Larvae are also pelagic, and all life stages feed largely on plankton. Thread herring also serve as important prey species for piscivorous coastal fishes and sea birds.

Table 2-2. Summary of habitats used by different life stages of economically and ecologically important fish and epibenthic invertebrate species of the southwestern Florida coast.

C = Coastal/Offshore; E = Estuary/seagrass; R = Rock/Reef Substrate; S = Sand/Mud Substrate; P = Pelagic

Common Name	Spawning Habitat	Juvenile Habitat	Adult Habitat
Striped Mullet	C	E	E,C,P
Red Grouper	C	C,R	C,R
Thread Herring	C	C,E,P	C,E,P
Ladyfish	C	E	E
Gag Grouper	C	E	C,R
Yellowedge Grouper	C	C,R	C,R
Jack Crevalle	C	C,P	C,P
Amberjack	C	C,R,P	C,R,P
Mojarra (various species)	C	C,E,S	C,E,S
Black Grouper	C	C,R	C,R
Scamp	C	C,R	C,R
Grunts	C	C,E,R	C,E,R
Mutton Snapper	C	C,R	C,R
Pompano	C	C,D/P	C,D/P
Sheepshead	C	E,R	E,R
Snowy Grouper	C	C,R	C,R
Gray Snapper	C	E,R	C,R
Spanish Mackerel	C	C,P	C,P
Red Snapper	C	C,R/S	C,R
Pinfish	C	E,S	E,C,S
King Mackerel	C	C,P	C,P
Spotted Seatrout	E	E	E
Flounders	C	C,E,S	C,E,S
Red Drum	C/E	E	C,E
Common Snook	C/E	E	C,E
Tarpon	C	E	C,E
Sea Robins	C	C,E,S	C,E,S
Pink Shrimp	C	E,S	C,E,S
Blue Crab	C	E,S	C,E,S
Stone Crab	C	C,E,S	C,E,S
Rock Shrimp	C	C,S	C,S

Table 2-3. Spawning seasons of fish and invertebrate species along the southwestern Florida coastline. X = peak spawning period.

Common Name	J	F	M	A	M	J	J	A	S	O	N	D
Striped Mullet	X										X	X
Red Grouper			X	X	X							
Thread Herring			X	X	X	X	X					
Ladyfish									X	X	X	
Gag Grouper		X	X									
Yellowedge Grouper				X	X							
Jack Crevalle				X	X	X						
Amberjack			X	X	X	X	X					
Black Grouper	X	X	X									
Scamp												
Grunts			X	X	X	X						
Mutton Snapper					X	X	X	X				
Pompano			X	X	X				X	X	X	
Sheepshead	X	X									X	X
Snowy Grouper												
Gray Snapper					X	X	X	X				
Spanish Mackerel					X	X	X	X				
Red Snapper						X	X					
Pinfish	X	X									X	X
King Mackerel					X	X	X	X	X	X		
Spotted Seatrout				X	X	X	X	X	X	X		
Flounders	X	X									X	X
Red Drum									X	X		
Common Snook					X	X	X	X	X	X		
Tarpon					X	X	X	X				
Sea Robins				X	X	X	X	X	X			
Pink Shrimp			X	X	X	X	X	X	X	X		
Blue Crab												
Stone Crab				X	X	X	X	X	X			
Rock Shrimp	X										X	X

Spanish mackerel (*Scomberomorus maculatus*) – This schooling species migrates along the Florida coastline and is found in the central western coast by late spring (FWRI, 2005). These piscivorous fishes spawn from May through August. Juvenile Spanish mackerel feed on small schooling fishes including striped anchovies, menhaden, and herring (Naughton and Saloman, 1981). Most of the 38,700 pounds taken in the 2005 commercial fishery were landed in Pinellas County. Over 2.2 million Spanish mackerel were captured by the recreational fishery in west Florida in 2005.

Ladyfish (*Elops saurus*) – Adult ladyfish live primarily in estuaries along Florida's coastline but are thought to spawn offshore during the fall (Wheeler, 2000). Their leptocephalus larvae recruit through tidal inlets to estuarine marshes that comprise their primary nursery habitats. The taxonomic status of ladyfish is presently uncertain and the current species may ultimately be split into two different species (Smith, 1989). The regional commercial fishery took nearly 1.3 million pounds in 2005 with most landings in Pinellas, Manatee, and Lee Counties. Ladyfish are also captured by the recreational fishery but those landings data are not available.

Tarpon (*Megalops atlanticus*) - Tarpon are one of the most popular recreational fishery species of Florida. The no-take fishery is widespread, supporting numerous tournaments and a large charter guide industry. Boca Grande Pass and the rest of the Florida Gulf Coast are famous for tarpon fishing. Adults feed primarily on fish and crabs and spawn offshore during full moon periods from May through August (Crabtree, 1995; Shenker et al., 2002). Precise spawning locations are unknown. Crabtree (1995) reported the presence of newly hatched leptocephalus larvae 200 km west of Sarasota while fishing guides catch ripe individuals in Boca Grande Pass and report apparent spawning behavior immediately outside the Pass. Larvae drift for approximately 20 days before entering estuaries where they use fringing marshes as nurseries.

Demersal Fishery Species

The demersal fish fauna off west central Florida includes dozens of species of considerable commercial and recreational value as well as a multitude of forage taxa that serve as important trophodynamic links in the coastal ecosystem. Demersal fishes are often associated with specific substrates (e.g., rock or coral reefs, oyster bars, seagrasses, sand, or mud), and many undergo predictable ontogenetic shifts in their preferred habitat. Most reproduce by producing pelagic eggs or larvae that are dispersed in coastal currents. Juveniles settle on specific nursery substrates and transition to adult habitats as they mature. The most important commercial and recreational demersal fishery species of west central Florida include:

Red grouper *(Epinephelus morio)* – The red grouper was the second most important commercial finfish species of the region in 2005 with nearly 3.6 million pounds landed at southwest Florida ports. Almost the entire regional catch was reported from Manatee, Pinellas, and Lee Counties. The red grouper also supports a major recreational fishery with over 1.8 million fish captured in western Florida in 2005.

Adult red grouper primarily inhabit reef structures in waters deeper or at least 60-100' deep and feed on small fish, crabs, shrimp, lobsters, octopus, and squid (Moe, 1969; FWRI, 2005). Like many other groupers, red grouper are protogynous hermaphrodites, beginning adult life as females and changing sex to males with age. Spawning occurs along the west Florida coast from January through June with peak activity from March to May. Their planktonic eggs and larvae drift through the coastal ocean until settlement. Juveniles inhabit shallower reefs (10 – 60 ft) and feed primarily on small crustaceans.

Gag grouper (*Mycteroperca microlepis*) – Gag groupers are one of the most valuable fishes throughout coastal Florida and support significant commercial and recreational fisheries. Over 1.2 million pounds were landed by regional commercial fishers in 2005 and over 2.8 million fish were taken by recreational anglers throughout western Florida. Over 85% of regional commercial landings were made in Pinellas County.

These protogynous hermaphrodites spawn in aggregations around structures, along the outer continental shelf from December through April with peak spawning activity in February and March (Bullock and Smith, 1991; Hood and Schlieder, 1992; Collins et al., 1998; Koenig et al., 2000). Larvae are transported across the shelf and utilize coastal seagrass beds as their juvenile habitat. As fish mature, they migrate progressively further offshore, inhabiting reef and hard bottom substrates to depths of 150 m or more. Juveniles and adults primarily feed on fishes with crustaceans making up a secondary component of their diet.

Gray snapper (*Lutjanus griseus*) – Gray snapper support large commercial and recreational fisheries around much of Florida's coastline. Pinellas County was the primary port for the 78,000 pounds of gray snapper landed in the region in 2005. Additionally, over 5.6 million gray snapper were captured by the recreational fishery in western Florida in 2005.

Adult gray snapper associate with hard bottom habitats along the continental shelf and form large spawning aggregations during summer (Domeier et al., 1996). Their pelagic larvae are transported to inshore nurseries in estuaries and back-reef environments where they inhabit mangrove fringes, seagrass beds, and other structures. Juveniles feed primarily on small shrimp and adults feed on fish, shrimp, and crabs (Hettler, 1989).

Red snapper (*Lutjanus campechanus*) – One of the most prized recreational and commercial fishes in Florida, adult red snapper associate with rock reef structures. Populations are most abundant in Northeast Florida and the Panhandle but they are also taken in the southwest Florida. Over 71,000 pounds were landed by the commercial fishery in this region in 2005, primarily in Pinellas County, and over 1.4 million fish were taken by the recreational fishery in western Florida.

Adult red snappers spawn April through January with a peak of reproductive activity in June and July (Bradley and Bryan, 1975). Juveniles settle in sand, seagrass, and on hard bottom (where they comprise a major portion of the bycatch of the trawl fishery for shrimp) and consume a variety of small crustaceans and cephalopods. As they mature, their diet expands with age to include many species of fishes.

Flounders (*Paralichthys* spp.) - Although available landings data do not discriminate among the different flounder species, the majority of flounders landed along the western Florida coast are probably the gulf flounder, *P. albigutta*. These benthic predators feed on small fish and crustaceans and inhabit sand substrate in estuaries and coastal waters. They spawn offshore in late fall and winter (FWRI, 2005). Over 272,000 flounders were taken by the recreational fishery in western Florida in 2005 and small numbers were landed by the commercial fishers in Pinellas, Lee, and Manatee Counties.

Red drum (*Sciaenops ocellatus*) – The commercial fishery for red drum in Florida was eliminated in the 1990s following population declines linked to severe overfishing. The species now supports a thriving recreational fishery with over 2.5 million fish taken by anglers in western Florida in 2005. In the Gulf of Mexico, juvenile red drums are most common in estuaries and adults migrate to coastal waters with maturity. Red drums spawn from August through November with peak spawning generally occurring in both nearshore waters and tidal inlets from August to October (Peters and McMichael, 1987; Murphy and Taylor, 1990). After drifting in the coastal ocean for up to several weeks, larvae recruit to estuarine nursery habitats. Juveniles feed on small crustaceans and adults forage on a wide variety of crustaceans and fish.

Common Snook (*Centropomus undecimalis*) – Snook are extremely popular sport fish species, common to rivers, estuaries, and nearshore marine waters of southwest Florida. These fish are protandric hermaphrodites, starting adult life as males and ultimately changing into females. Snook spawn in estuarine inlets from April into October, releasing larvae into ebbing tidal currents (Taylor et al., 1998). Larvae recruit back through inlets, settling as juveniles in rivers and fringing marshes. Although highly prized by anglers in Tampa Bay, Sarasota Bay, and other estuaries, recreational landings data are not available.

Demersal Forage Species

Small-bodied demersal fishes are often extremely abundant and thus form critical links in the trophic structure of coastal regions by feeding on epifauna and infaunal invertebrate species and by serving as prey for larger piscivores. Demersal forage species that are of special importance on the West Florida shelf include:

Grunts (Haemulidae) – Grunts are a diverse fish family that are prey for larger piscivores including groupers and snappers (FWRI, 2005). Common species of grunts inhabiting Florida's west coast include pigfish (*Orthopristis chrysoptera),* which is generally associated with shallow seagrass, as well as the white grunt (*Haemulon plumieri*) and tomtate (*H. aurolineatum*), which achieve greatest abundance in nearshore waters (Pierce and Mahmoudi, 2001). Most grunts generally associate with low-relief rock and coral structures during daylight but may make predictable nocturnal movements to open sand and seagrass to forage on benthic invertebrates (Meyer and Schultz, 1985). Many grunt species spawn during the spring but can have extended spawning seasons in offshore waters. Over 146,000 pounds of grunt were taken by the commercial fishery in 2005 with landings concentrated in Pinellas County. Catches of this family also support an important recreational fishery for pan and bait fish with over 3.9 million fish taken in 2005.

Porgies (Sparidae) – Porgies are a diverse family of forage fishes although some larger species are targeted by the recreational fishery. Most commercial and recreational landings of porgies are for use as bait and the largest fishery is for pinfish (*Lagodon rhomboides*). The regional commercial pinfish fishery is centered in Pinellas and Hillsborough Counties with landings of over 32,000 pounds in 2005. An estimated 9 million pinfish were captured by recreational anglers in western Florida in 2005. Adult pinfish live in estuaries or in nearshore waters, generally in seagrass or patchy hard bottom habitats. They spawn offshore in late fall and winter, and larvae are transported into estuarine nursery habitats (Nelson, 2002). Juveniles feed primarily on crustaceans and adults are one of the few Florida marine fishes that feed extensively on macroalgae and seagrasses.

Seven porgies of the genus *Calamus* are also common along the west Florida coast although their life history has not been extensively studied. The knobbed porgy, *C. nodosus*, is known to spawn May through June off the Carolinas and utilize a diet of polychaetes as well as hard-shelled invertebrates including mollusks, crustaceans, and echinoderms that they crush with their strong jaw and pharyngeal teeth (Horvath et al., 1990).

Mojarras (Gerreidae) – Mojarras are abundant in coastal and estuarine waters throughout Florida (Motta et al., 1995; Pierce and Mahmoudi, 2001; Poulakis et al., 2004). Their highly protrusible jaw makes them effective suctorial predators on small benthic organisms such as polychaetes, amphipods, and small bivalves (Motta et al., 1995; Nordfors, 2001). Although spawning seasonality of mojarras has not been directly studied, the appearance of small juveniles in coastal Florida estuaries during summer (Poulakis et al., 2004) suggests that adults spawn offshore in spring and early summer. Mojarras are presumed to be important prey for many demersal piscivores and are widely used as bait by anglers targeting snook, snapper, and grouper.

Sea Robins (Triglidae) – Eight sea robin species are frequently collected with trawls along the western Florida shelf (Ross, 1983). Their consumption of benthic organisms, including small crustaceans, polychaetes, and lancelets, and their role as prey for larger piscivorous fishes, make them a potentially significant link in the food web associated with sand borrow sites (Ross 1977, 1978). Different species of sea robins spawn at different times of the year but reproduction peaks from spring through late summer (Ross, 1983; McBride, 2002).

Lizardfish (Synodontidae) – Lizardfish are commonly found on shallow sandy substrates throughout tropical areas. Rarely exceeding 30 cm in size, lizardfish are lurking predators with pigmentation that provides them with excellent camouflage. Little is known of the life history of Florida species but given their presumed diet of small demersal fishes, lizardfish may be an important predator on new recruits and an important link in the trophodynamic structure of the coastal ecosystem as well as the population dynamics of individual species.

Bothid Flounders – In addition to commercially valuable flounders of the genus *Paralichthys*, Pierce and Mahmoudi (2001) documented many other small flatfish species along the western Florida shelf including whiffs (*Citharichthys* spp.), dusky flounder (*Syacium papillosum)*, and ocellated flounder (*Ancyclopsetta quadrocellata*). Although poorly studied, most species presumably feed on benthic invertebrates in sandy habitats and are prey for larger fishes.

Invertebrate Fishery Species

Pink shrimp (*Farfantepenaeus duorarum*) – Shrimp comprise the largest commercial fishery in western Florida. Pink shrimp are the dominant fishery species with over 7.6 million pounds landed regionally in 2005 (Appendix A). Lee County accounted for 63% of landings with Hillsborough and Pinellas Counties recording 23% and 14% of the catch, respectively. Brown shrimp (*Farfantepenaeus aztecus*) and white shrimp (*Litopenaeus setiferus*) are also an important, but generally smaller, component of the regional commercial penaeid shrimp fishery.

Adult pink shrimp are most common over coarse sandy sediments at depths of 35-120 feet. Spawning occurs throughout the year peaking in late spring through early fall with larvae recruiting to estuarine seagrass and salt marsh nurseries (Eldred et al., 1965).

Blue crab (*Callinectes sapidus*) – Over 3 million pounds of blue crabs were landed in western Florida in 2005 with peak landings in Lee County (44%) and Charlotte County (26%). Adults are generally harvested using wire traps set in estuaries and the nearshore coastal ocean. When female crabs are preparing to release zoea larvae from egg masses carried on their abdomens, they migrate to inlet mouths or along the coast northward toward the panhandle region of Florida (Steele, 1991). Larvae drift passively until they reach the megalops stage and begin the use of tidal currents to recruit to estuarine nursery habitats (Tankersley et al., 2002).

Stone crab (*Menippe mercenaria*) - The fishery for stone crabs focuses on harvesting claws and returning crabs alive to regenerate new claws and to reproduce. Stone crabs live in burrows in the benthos from the shoreline to depths of 200 feet and spawn primarily from April through September (Sullivan, 1979). Larvae settle in nearshore waters and estuaries. Over 241,000 pounds of claws were harvested in the region in 2005 with most landings occurring in Pinellas, Lee, and Manatee Counties.

Rock shrimp (*Sicyonia brevirostris*) – Rock shrimp are generally trawled from sand habitats in depths exceeding 100 feet. Nearly 211,000 pounds were landed in western central Florida in 2005 with most landings in Hillsborough, Lee, and Pinellas Counties. Rock shrimp spawn from November through January (FWRI, 2005).

2.6.3 Protected Fish Species

The ranges of two fish species protected under the Endangered Species Act, the Gulf sturgeon (*Ascipenser oxyrhynchus desotoi*) and smalltooth sawfish (*Pristis pectinata*), overlap sand resource borrow areas identified along the west Florida coast. Neither is likely to be locally abundant. The Gulf sturgeon is an anadromous fish that spawns in rivers from Mississippi to the west coast of Florida (Wakeford, 2001). Larger juveniles and adults often use estuarine and coastal areas where they feed on benthic organisms such as amphipods, lancelets, molluscs, crabs, shrimp, and polychaetes. Little is known about what types of substrates are preferred by this species when offshore, but the sand resource areas do support its primary prey. Gulf sturgeon populations have declined precipitously due to intense fishing pressure and degradation of freshwater spawning sites. The commercial fishery in Tampa Bay started in 1886 and the species virtually disappeared within 3 years. At present, Gulf sturgeon are only sporadically seen in Tampa Bay and only 7 sightings have been made in Charlotte Harbor over the last 40 years (Wakeford, 2001). Currently the species is most abundant in tributaries of the Florida panhandle.

The smalltooth sawfish originally inhabited coastal areas throughout Florida but populations declined as fish were killed incidentally in net fisheries or harvested for their distinctive rostrums that were sold as curios. In response, the smalltooth sawfish was listed as federally endangered in May 2003. In a study of the Everglades and Florida Keys sawfish population, Poulakis and Seitz (2004) determined that juveniles were generally restricted to estuaries and coastal waters less than 10 m deep but adults were taken as deep as 70-122 m. These piscivorous fish were generally found over muddy bottoms but they also utilized sand and seagrass habitats.

Although not federally listed, several other fishes identified by the State of Florida and National Marine Fisheries Service as overfished or prone to overfishing are currently prohibited from being harvested. These include the goliath grouper (*Epinephelus itajara*), Nassau grouper (*E. striatus*), spotted eagle ray (*Aetobatus narinari*), manta ray (*Manta birostris*), and 18 species of shark. With the exception of goliath grouper, all species are expected to be rare or transitory in the area of proposed borrow sites.

2.6.4 Sea Birds, Sea Turtles and Marine Mammals

Seabirds and Migratory Land Birds

Very few surveys completed in the Gulf of Mexico are dedicated to bird populations; however, many of the marine mammal surveys contain ancillary pelagic and migratory bird observations. In the Gulf, marine mammal movements and pelagic bird species are often associated with the increased primary productivity of the Loop eddies and cold core currents (Ribic et al., 1997; Wursig et al., 2000; Russel, 2005). More than 70 species have been observed in the Gulf of Mexico and the coastal regions of southwest Florida during studies dating from 1996 to 2005 (Davis, 1996; Davis et al., 2000; Avent, 2004; MJ Barkazsi personal communication, 2005; Russel, 2005). Population status and movements of pelagic bird species are difficult to determine as surveys must be conducted offshore in marine field conditions and bird movement is weather dependent.

Species observed in the Gulf are predominantly trans-migrant shorebirds, wading birds, and waterfowl that may occupy the study area briefly, if ever. This section addresses seabirds and transmigrants that may pass through the offshore habitats of the project area, or use the dredgers and boats for temporary resting places.

Seabirds

Federal regulatory protection of birds may fall under the Migratory Bird Treaty Act (MBTA) (16 U.S.C. §§ 703-712) and/or the U.S. Endangered Species Act (ESA) § 9(a) (1) (B). All birds listed in the Gulf studies are protected under the MBTA. These include members of the Seabird guild, which represents a wide range of species dependent on the resources of the pelagic zone of the Gulf of Mexico. Much of their time is spent in or over water and they are capable of staying far from land for long periods. Most of these birds have adaptive salt glands that allow them to regulate the salt content in their blood (Ehrlich et al., 1988). A majority of species in this guild are colonial nesters that leave the nest to venture far from natal areas. Some seabirds spend significant portions of their life cycle offshore and may occur in the study area, such as Magnificent Frigatebird (*Fregata magnificens*), Greater Shearwater (*Puffinus gravis*), Sooty Shearwater *(P. griseus)*, Audubon's Shearwater *(P. lherminieri)*, and Manx Shearwater *(P. puffinus)*, Masked Booby *(Sula dactylatra)*, Northern Gannet (*Morus bassanus),* Wilson's Storm-Petrel (*Oceanites oceanicus)*, and Band-rumped Storm- Petrel (*Oceanodroma castro)*. While gulls and terns, pelicans, and cormorants divide their time more or less equally between offshore and coastal waters (Ehrlich et al., 1988) the may also occur in the study area. Birds, such as Brown Noddy (*Anous stolidus)*, Black Tern (*Chlidonias niger)*, Herring Gull *(Larus argentatus)* and Laughing Gull *(Larus atricilla),* Bridled Tern *(Sterna anaethetus)*, Least Tern *(Sterna antillarum)*, Common Tern *(Sterna hirundo)*, Artic Tern *(Sterna paradisaea)*, Sandwich Tern *(Sterna sandvicensis)*, Caspian Tern *(Sterna caspia),* Forster's Tern *(Sterna forsteri)*, Royal Tern *(Sterna maxima)*, and Gull-billed Tern *(Sterna nilotica)*, and Brown Pelican *(Pelecanus occidentalis)* may occur in the study area.

Migrants

The west Florida coast serves as a principal route of the Atlantic Flyway for more than 60 migratory landbird species. Many of the birds that breed east of the Allegheny Mountains move southwestward in fall, through northwestern Florida, crossing the Gulf to the coastal regions of eastern Mexico where they follow a land route for the remainder of the journey to Cuba or South America (Lincoln et al., 1998). Many of the migrants that could pass through the study areas are unlikely to stop except to rest on a dredge or boat during migration. Under this condition, all are protected by MBTA. There are no resident endangered birds in the study area.

Sea Turtles

Five species of sea turtles are likely to occur off the west coast of Florida (Meylan and Meylan, 1999; FWRI FWC, 2007): leatherback (*Dermochelys coriacea*), green (*Chelonia mydas*), loggerhead (*Caretta caretta*), hawksbill (*Eretmochelys imbricate*), and the Kemp's Ridley (*Lepidochelys kempii*). Marine turtle adaptation to sea life and nesting behaviors has changed little since they evolved 200 million years before present. Generally, in the first 20-30 years of life sea turtles cycle through phases of pelagic and inshore feeding before reaching adult sexual maturity. Female adults briefly move onshore to nest on beaches then return to the ocean. The adult turtle diet may change in correspondence with habitat preference and migration patterns from seaweed, to the infauna associated with seaweed and algae to more complex animals such as jellyfish, molluscs, and crabs. Migration tracks of individual adults and juveniles while feeding and nesting may be observed in real time by satellite telemetry (Mote Marine Laboratory et al., 2005). Phase(s) of the life cycle spent on the west coast of Florida may be brief and overlapping as it is not specific to each species.

All sea turtles are protected under the Endangered Species Act (ESA). Turtles may fall under multiple agency jurisdictions depending upon the turtle's life cycle stage and its location. Turtles in the water are under the jurisdiction of NOAA Fisheries, while nesting turtles and their subsequent eggs and hatchlings are under USFWS jurisdiction. In recent years, critical habitat has been established for some turtle species in the U.S. Virgin Islands and Puerto Rico; no critical habitat has been designated in the study area.

Table 2-4 lists the five species of marine turtles documented in the Gulf of Mexico, the protection status of each, and nesting and/or seasonal presence in the Gulf. Between 1990 and 2006, three of the five species nested in one county of the study area at least once. From 1979 to 2006, no nests have been recorded for Hawksbills in any county located in the study areas (FWRI FWC, 2007). Nesting data may

Table 2-4. Sea Turtles of the Gulf of Mexico.

Common Name	Scientific Name	Seasonal Presence	Status [b]
Giant Leatherback	*Dermochelys coriacea*	+Year round: [a] Nests (March - July)	E
Green Sea Turtle	*Chelonia mydas*	+Year round: [a] Nests (June - September)	E
Loggerhead	*Caretta caretta*	+Seasonal: [a] Nests (May – August)	T
Hawksbill Turtle	*Eretmochelys imbricate*	Year round: [a] Nests (April – November)	E
Kemp's Ridley Turtle	*Lepidochelys kempii*	+ Year round: [a] Nests (April – June)	E

+ Present in project area counties (USFWS 2000)
[a] nests counts available for 2006 in study area (FWC 2007)
[b] USFWS 2007

be obtained from the Florida Wildlife Research Institute (FRWI) at http://research.myfwc.com. Information for each species that is likely to occur in offshore of central southwest Florida is discussed below. The absence or presence of nests varies in location by species.

Leatherback Turtle

The Leatherback Turtle, the largest of sea turtles, is an endangered species and can reach 8 ft. in length and weigh 2,000 lbs. Populations occur in the Atlantic, Pacific, and Indian Oceans and in the Gulf of Mexico with few nesting records from southwest Florida and no records between 1979 and 1992 (Meylan et al., 1995; FWC, 2005). Pelagic and migratory, they are rarely seen nearshore outside of nesting activity (Wynne and Schwartz, 1999). Between 2001 and 2004, four leatherback nests were reported in southwest Florida, three in Monroe County and one in Sarasota County and no nests were reported in 2006 (FWRI FWC, 2007). Leatherbacks prefer a staple diet of jellyfish, which they supplement with sea urchins, squid, crustaceans, tunicates, fish, blue-green algae, and floating seaweed (USFWS, 2004).

Green Sea Turtle

There are multiple populations of Green Sea Turtles worldwide in the Caribbean, Pacific, Indian Ocean, and the U.S. Green sea turtle populations occur in the U.S. Virgin Islands, Puerto Rico, and from Texas to Massachusetts (NOAA, 2005). Green sea turtle populations in Florida and the Pacific coast of Mexico are listed as endangered by the USFWS (USFWS, 2007). They use the coastal waters of all southwest Florida counties in the study area (USFWS, 2005). The Green sea turtle is a year-round resident of Florida waters. Although nesting is concentrated on the Florida East Coast, between 1988 and 2004, approximately 100 Green sea turtle nests were documented from southwest Florida beaches (Meylan et al., 1995; FWRI FWC, 2005). In 2006 there were 7 Green sea turtle nests scattered in all Southwest Florida counties except Collier (FWRI FWC, 2007). Green sea turtles have both pelagic and coastal phases: young turtles are herbivores feeding on seagrasses and algae in coastal areas, as adults they feed on seagrasses and expand their diet to benthic fauna such as crabs and molluscs. Important feeding grounds north of the study area and in state waters include Homosassa, Crystal River, and Cedar Key (NOAA, 2005).

Loggerhead Turtle

Populations of Loggerheads are distributed worldwide in the Atlantic, Pacific, and Indian Oceans. Analysis of mitochondrial DNA has identified the South Florida Subpopulation as one of five subpopulations in the western North Atlantic occurring from north of Cape Canaveral on Florida's east coast and extending into the Gulf of Mexico to Sarasota, FL (USFWS, 2004). Loggerheads are the most numerous of the sea turtles that nest along the southwest coast. In 2006, there were 3,410 Loggerhead nests for all study area counties (FWRI FWC, 2007). Loggerheads have been spotted in deep water areas of the Gulf where depths exceed 1000 m (GeoCet, 2005). They are frequent visitors of offshore platforms and linger around them for long periods of time (Gitchleg, 1994; GeoCet, 2005). In addition to the time spent offshore, they venture into estuaries to feed on crustaceans and benthic invertebrates. They also use coral reefs, rocky bottom, and shipwrecks as feeding areas (USFWS, 2004). In 2002, a petition was submitted and reviewed to recognize the Northern and Florida Panhandle subpopulations as distinct population segments, to change their listed status from threatened to endangered, and to designate critical habitat. NOAA deemed the petition to have substantial scientific evidence to merit a review later in September 2003, USFWS and NMFS denied the petition (Federal Register 2002:2003). Presently, all Loggerhead subpopulations are listed as threatened by the USFWS (USFWS, 2007).

Hawksbill Turtle

The Hawksbill turtle inhabits the Atlantic, Pacific, and Indian Oceans and is listed as endangered by the USFWS (USFWS, 2007). In the continental U.S., the Hawksbill is present in the coastal Gulf waters of Texas and areas near the Florida Keys; however, no nests have been reported in the study area. Nesting occurs in low densities between April and November on scattered small beaches of the Caribbean Sea and in Monroe and Manatee Counties, south and north of the study area (FWRI, 2007). Post hatchlings are pelagic, taking cover in seaweed mats or weedlines found at convergence lines. Their diet of sponges, found on rocky outcrops on high-energy shoals attracts them to coral reefs, ledges, and caves as juveniles, subadults, and adults. Where coral reefs are absent, they may use estuaries and mangrove-edged bays (NOAA, 2005).

Kemp's Ridley Turtle

The Kemp's Ridley sea turtle is one the world's smallest sea turtles (length 2 ft, weight 100 lbs) and is common throughout the Gulf coasts of Mexico and the U.S., and the Atlantic eastern seaboard as far north as Nova Scotia and Newfoundland (USFWS, 2004). Although this species can tolerate cooler temperatures than other sea turtles, they are often cold-stunned and become stranded if they do not migrate early enough from northern ranges (Wynne and Schwartz, 1999). Some single nests have occurred on Florida beaches. Most nesting occurs in mass groups on a few beaches in Mexico from April to June. Kemp's neonatal juveniles are pelagic, feeding on epipelagic species, and/or sargassum and the infauna inhabitants for about 2 years, before traveling to coastal waters. Like the loggerhead, the Kemp's Ridley enters estuaries and harbors to feed on swimming crabs, shrimp, and molluscs (USFWS, 2004; NOAA, 2005). Onshore from the study areas only 3 Kemp's Ridley nests have been documented in Lee and Sarasota Counties from 1990-2006 (FWRI, 2007). The Kemp's Ridley is listed as endangered by the USFWS (USFWS, 2007).

Marine Mammals

Studies of marine mammals in the Gulf of Mexico began in the early 1970s in waters of the continental shelf. In the 1980s and 1990s the MMS and NMFS conducted aerial and vessel surveys in deep waters near the slope where greater species diversity was documented (Lang et al., 2000; Wursig et al., 2000). Although data exist on coastal populations of common marine mammal species, such as Bottlenose Dolphins, Atlantic Spotted Dolphins, and Florida Manatee, until the 1980s these marine mammal records were from historic hunting or stranding records. Much of the impetus to gather more information on marine mammals is due to increased human activities, namely oil and gas operations, throughout the Outer Continental Shelf (OCS) and into deeper regions of the Gulf. Several marine mammal surveys initiated in the past are continuing under cooperative agreements among MMS, NMFS, USGS - Biological Resource Division, and the Office of Naval Research. Some of those surveys used in this report are the "Fritts Surveys" conducted by USFWS, the MMS GulfCet Program, the MMS Sperm Whale Seismic Study (SWSS), and other studies completed in conjunction with energy searches (Fritts, 1983; Davis et al., 1996; Wursig et al., 2000; Davis et al., 2000; Jochens et al., 2003; Advent, 2004; GeoCet, 2005). These studies were conducted in the western, central, and northeastern areas of the Gulf and documented the feeding, reproductive activities, and the migratory pathways for the marine mammal species that occupy deep water habitats. The data from the earlier marine mammal species records and more recent NMFS, USFWS, and FWRI FWC information for the west coast of Florida were reviewed to identify the marine mammal species likely to be present near the study area.

The 29 marine mammal species sighted in the Gulf of Mexico at least once during the last 100 years were evaluated for their potential to be present near the study sites. Species were eliminated from consideration if sightings were stranding records only, sightings were outside of the study area, and/or the preferred habitat was outside the (OCS) or in estuarine waters.

All marine mammals are protected under the Marine Mammal Protection Act (MMPA) of 1972 and are under the jurisdiction of NOAA Fisheries. The MMPA prohibits, with certain exceptions, the take of marine mammals in U.S. waters (NOAA Fisheries, 2005).

Listed Species

Northern Right Whale

Endangered and rare, the Northern Right Whale (*Eubalaena glacialus*) was described as a single species until recent genetic studies identified the North Atlantic Ocean and North Pacific Ocean populations as different species (Best et al., 2001; Federal Register 2003). Northern Right Whales range from Iceland to eastern Florida, primarily in coastal waters. The North Atlantic population is estimated at approximately 300 individuals (NMFS, 2007). Coastal waters of the southeastern U.S. (off Georgia and northeast Florida) are important wintering and calving grounds, while the waters around Cape Cod and the Great South Channel are feeding, nursery, and mating habitat during summer (Kraus et al., 1988; Schaeff et al., 1993). From June to September, most animals are found feeding north of Cape Cod. Southward migration occurs offshore from mid-October to early January (Kraus et al., 1993). Migration northward along the Mid-Atlantic coast takes place during late winter and early spring (NMFS, 1996). Designated critical habitat for the northern right whale does not occur in the study area.

A Right Whale sighting occurred in the study area, off New Pass, Sarasota, on March 10, 1963, when two Right Whales were recorded swimming in waters approximately 10 m deep (Moore and Clark, 1963). NMFS (2006) views the records from the Gulf of Mexico and a record from 1999 in Norway as either geographic anomalies or that Right Whales have a more extensive historic range beyond the sole known calving and wintering grounds off of the southeastern United States (Waring et al., 2004). It is unlikely that this species would occur in the study area.

Sperm Whale

The endangered Sperm Whale (*Physeter macrocephalus*) is one of the most common whales found in the Gulf of Mexico. The latest Sperm Whale population estimate for the northern Gulf is 1,114 - 1,349 (NMFS, 2005). Sightings have occurred along the south Florida coast, between Florida and Cuba and in the open offshore waters of the Gulf of Mexico (Schmidly, 1981). These whales prefer deep water (600 m or more) and according to the NOAA Stock Assessment Reports (2005) are unlikely to be found in water less than 300 m deep. Most survey sightings have occurred at or near the 200 m contour and over the slope (Wursig et al., 2000). Sightings from observers performing mitigation measures on offshore installations list Sperm Whales as the second most common marine mammal recorded during surveys (GeoCet, 2005). Sperm Whales travel alone or in groups of up to 35 - 40 feeding on organisms such as squid, octopus, sharks, cod, scorpaenids, barracuda, and sponges (Schmidly, 1981). There is no conclusive evidence to confirm or refute the negative impact of underwater noise from humans on marine mammal populations (MMS, 2007). In areas offshore of Alaska and the South Atlantic, takes are primarily caused by collisions with vessels and entanglement with longline fishing according to a Draft OCS EIS/EA (MMS, 2007).

Florida Manatee

The Florida Manatee (*Trichechus manatus*), a federally listed endangered species native to coastal Florida waters, is one of three sirenian species throughout the world. The basis for its endangered status is the number of documented mortalities (natural and human-related) relative to the estimated population level, and the continuing severe threats to critical manatee habitats in the southeastern U.S. (USFWS, 2005). Annual synoptic surveys estimate the population between 2,000 – 3,000 individuals (Wursig et al., 2000). Manatees are opportunistic herbivores that feed on submerged and emergent aquatic vegetation; thus, they are predominately restricted to coastal habitats. Water temperatures drive manatee movements inland from colder to warmer waters of natural springs and artificial warm water sources, such as power plant effluents (FWC, 2005). Although individuals are known to have traveled west to Texas probably in coastal waters (USFWS, 2007), it is unlikely that manatees will occur within or near the study areas.

Other Listed Species

Numerous species were considered "extralimital" or known to occur in the Gulf of Mexico only by accident or during unusual circumstances. Marine mammal species listed as endangered and considered extralimital the Blue Whale (*Balaenoptera musculus*), Fin Whale (*Balaenoptera physalus*), Sei Whale (*Balaenoptera borealis*), Bryde's Whale (*Balaenoptera edeni*), and Humpback Whale (*Megaptera novaeangliae*).

Non-listed Species

Nearly all of the non-listed cetaceans mentioned below rarely occur in waters less than 100 meters deep unless stranded, and some are known to inhabit water depths of 2,000 meters. This group includes Minke Whale (*Balaenoptera acutorostrata*), Pygmy Sperm Whale (*Kogia breviceps*), Dwarf Sperm Whale (*Kogia simus*), Cuvier's Beaked Whale (*Ziphius cavirostris*) and other Beaked Whales: Blainville (*Mesoplodon densirostris*), Sowerby (*M. bidens*), and Gervais (*M. euopaeus*). Members of the family Delphinidae not listed and unlikely to occur in the study area are the Killer Whale (*Orcinus orca*), Short-finned Pilot Whale (*Globicephala macroryhnchus*), False Killer Whale (*Pseudorca crassidens*), Pygmy Killer Whale (*Feresa attenuata*), and Melon-headed Whale (*Peponocephala electra*).

Various dolphins inhabit the inner continental slope and coastal waters from 10 m to 200 m depth, such as the Atlantic Bottlenose Dolphin (*Tursiops truncatus*) and the Atlantic Spotted Dolphin (*Stenella frontalis*) (NOAA Fisheries, 2005). Both populations are estimated at more than 20,000 individuals. Additional non-listed species observed in deep waters of the Gulf of Mexico but unlikely to occur in the study area are dolphin species: Rough-toothed Dolphin (*Steno bredanesis*), Risso's Dolphin (*Grampus griseus*), Pantropical Spotted Dolphin (*Stenella attenuate*), Spinner Dolphin (*Stenella longirostris*), Clymene Dolphin (*Stenella clymene*), Striped Dolphin (*Stenella coeruleoalba*), and Frasier's Dolphin (*Lagenodelphis hosei*). The populations of deep water dolphin species range from 200 to thousands of individuals. Although all are protected by the Marine Mammal Protection Act, none listed above are protected under the ESA.

2.7 Harmful Algal Blooms

Any evaluation of the function and value of marine habitats off southwest Florida must consider the role of episodic blooms of the toxic dinoflagellate *Karenia brevis*. These outbreaks, typically referred to as harmful algal blooms (HABs) or red tides, can cause massive mortality of fishes and some invertebrates (FWRI, 2005). Deaths of sea turtles, manatees, and dolphins have also been attributed to prolonged exposure to HABs. Further, toxins released into the air along beaches can cause respiratory distress in humans, and consumption of bivalves contaminated with *K. brevis* can cause distressing but non-lethal neurotoxic shellfish poisoning.

HABs have been observed for hundreds of years along Florida's coastline and apparently are partially driven by natural processes as well as anthropogenic factors. Blooms frequently occur in the fall, starting 10-40 miles offshore on the mid-continental shelf and are subsequently transported by wind and currents, sometimes moving shoreward or along the shelf, and can persist for several months. The impacts of HABs are most dramatic for immobile or territorial fishes or those trapped in a region surrounded by a bloom. Large numbers of dead fish washing ashore or floating at the surface are commonly reported during an event. Benthic invertebrates are also affected, particularly hard-bottom corals, sponges, and echinoderms. Mortality may be the direct result of toxic exposure or precipitous drops in dissolved oxygen induced by respiration and decay of high densities of dinoflagellates.

Smith (1976) provided the most comprehensive documentation of the impacts of a HAB on reefs near Sarasota, showing that the bloom exterminated virtually all fish and invertebrates on many reefs. Recovery of fishes in the region occurred within 12-18 months but a recovery time of at least 2 to 5 years was expected for slow-growing corals and sponges. A major HAB occurred from August through September 2005 affecting habitats from Tarpon Springs to Sarasota (Figure 2-38). Smaller HABs were noted from 2001 to 2004, but another widespread HAB occurred in 2006 (www.floridamarine.org). HAB monitoring and research are major efforts of the Florida Fish and Wildlife Research Institute (FWRI). Results of monthly sampling from a series of stations along the Florida coastline as well as access to historical databases on the distribution and abundance of *K. brevis* are provided at www.floridamarine.org.

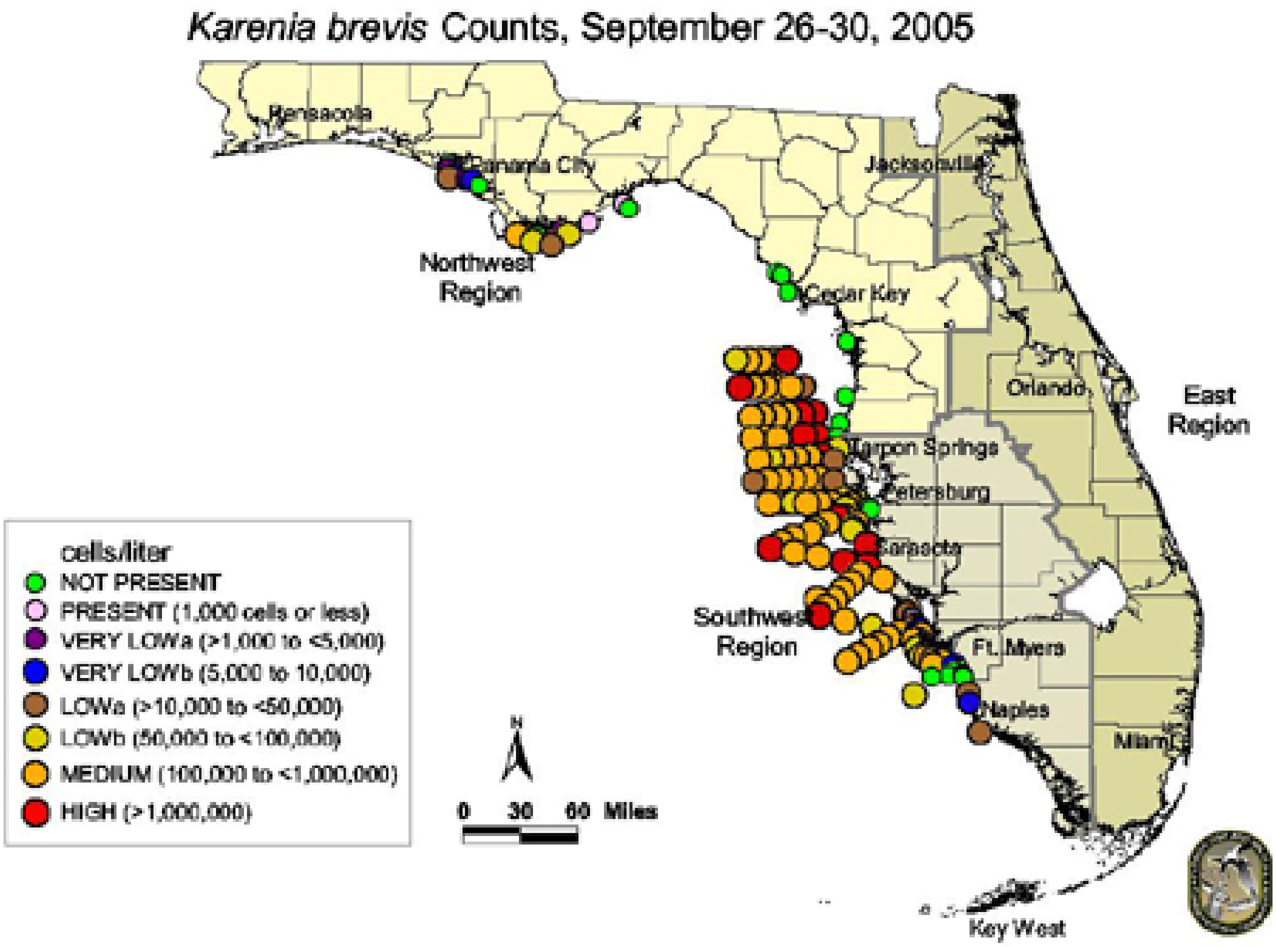


Figure 2-38. Abundance of the dinoflagellate Karenia brevis during a Harmful Algae Bloom that affected much of central western Florida in September 2005 (FWRI, 2005; www.floridamarine.org).

3.0 FIELD EVENTS 2005 AND 2006 FOR BIOLOGICAL AND SEDIMENT SAMPLING

3.1 Introduction

The purpose of the two field sampling events was to augment the literature research by characterizing the biological communities present on and off the shoals near the study areas. Sediment grab samples were taken using Smith McIntyre samplers to identify benthic organisms and to assess the sedimentary environment. Water quality indicators (salinity, temperature, chlorophyll-a, and dissolved oxygen) were determined from water column samples collected during the field events. Fishes and plankton were identified from samples collected using fish trawls and plankton tows. Observers were located on the field vessels to sight and document marine mammals, sea turtles, and sea birds during field events. A data management plan and a cruise plan developed prior to the first field event outlined the methods described in the next section.

3.2 Methods

The Fall 2005 field event was conducted from 3 - 7 October 2005 aboard the Florida Institute of Oceanography research vessel, RV *Suncoaster*. Field sampling included collection of 54 Smith McIntyre grabs (0.1 m^2); 9 CTD casts; epifauna video camera sled transects; and otter trawls and plankton tows described in Sections 3.2.1-3.3.5. Observers were onboard to record sightings of listed species. The locations of Fall 2005 benthic grab and otter trawls appear in Figures 3-1 and 3-2.

The Spring 2006 field event was conducted from 14 – 16 June 2006 aboard the research vessel, MV *Thunderforce*. Field sampling included: collection of 59 Smith McIntyre grabs (0.1 m^2) and 12 CTD casts; and otter trawls and plankton tows described in Sections 3.2.1 -3.3.5: Methods and Results. The locations of Spring 2006 benthic grab and otter trawls appear in Figures 3-3 and 3-4. Specific geo-position data for all benthic grabs, trawls, and video transects conducted during the project are provided in Appendix B.

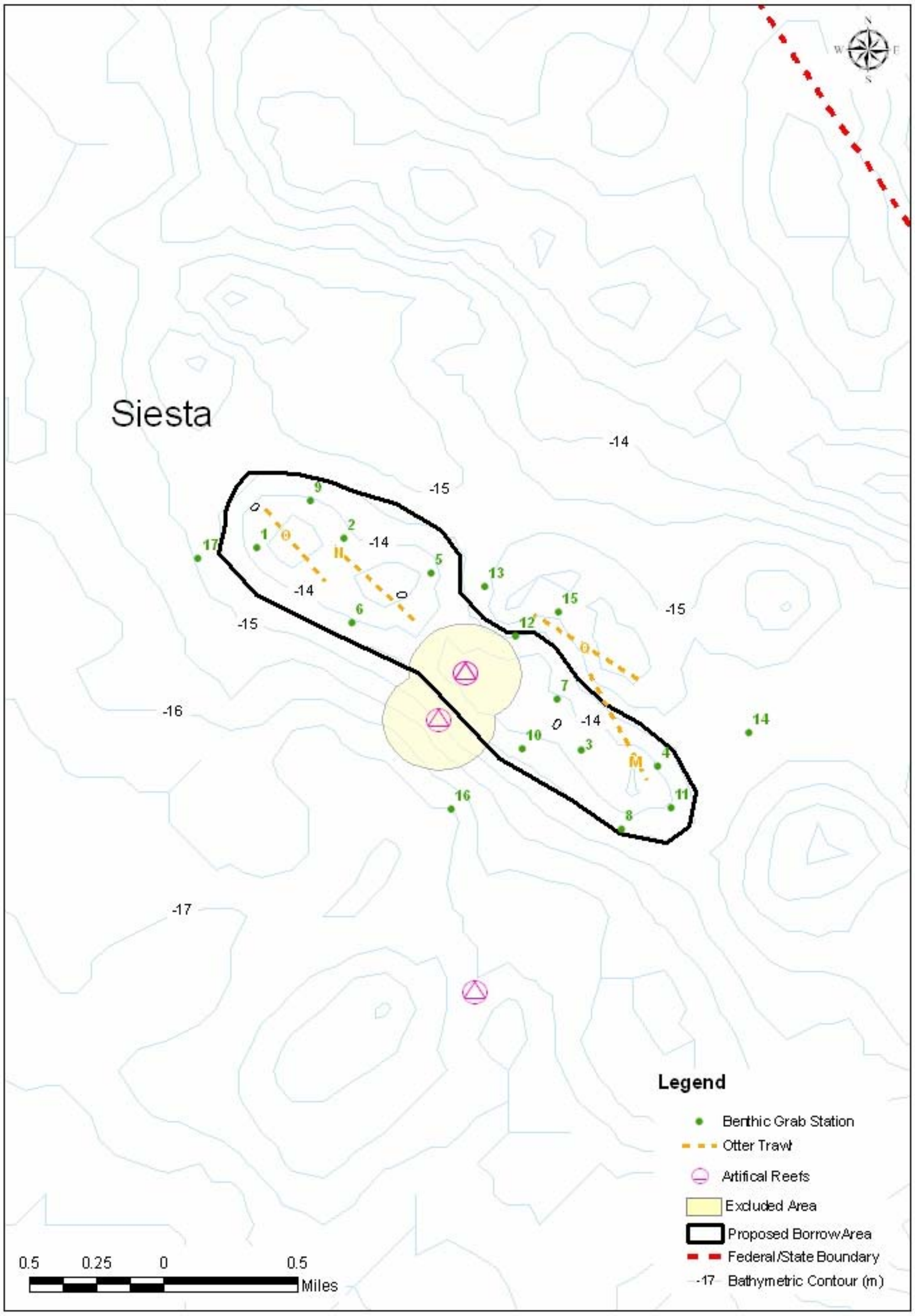


Figure 3-1. Locations of benthic grabs and otter trawls at the Siesta Shoal site, Fall 2005.

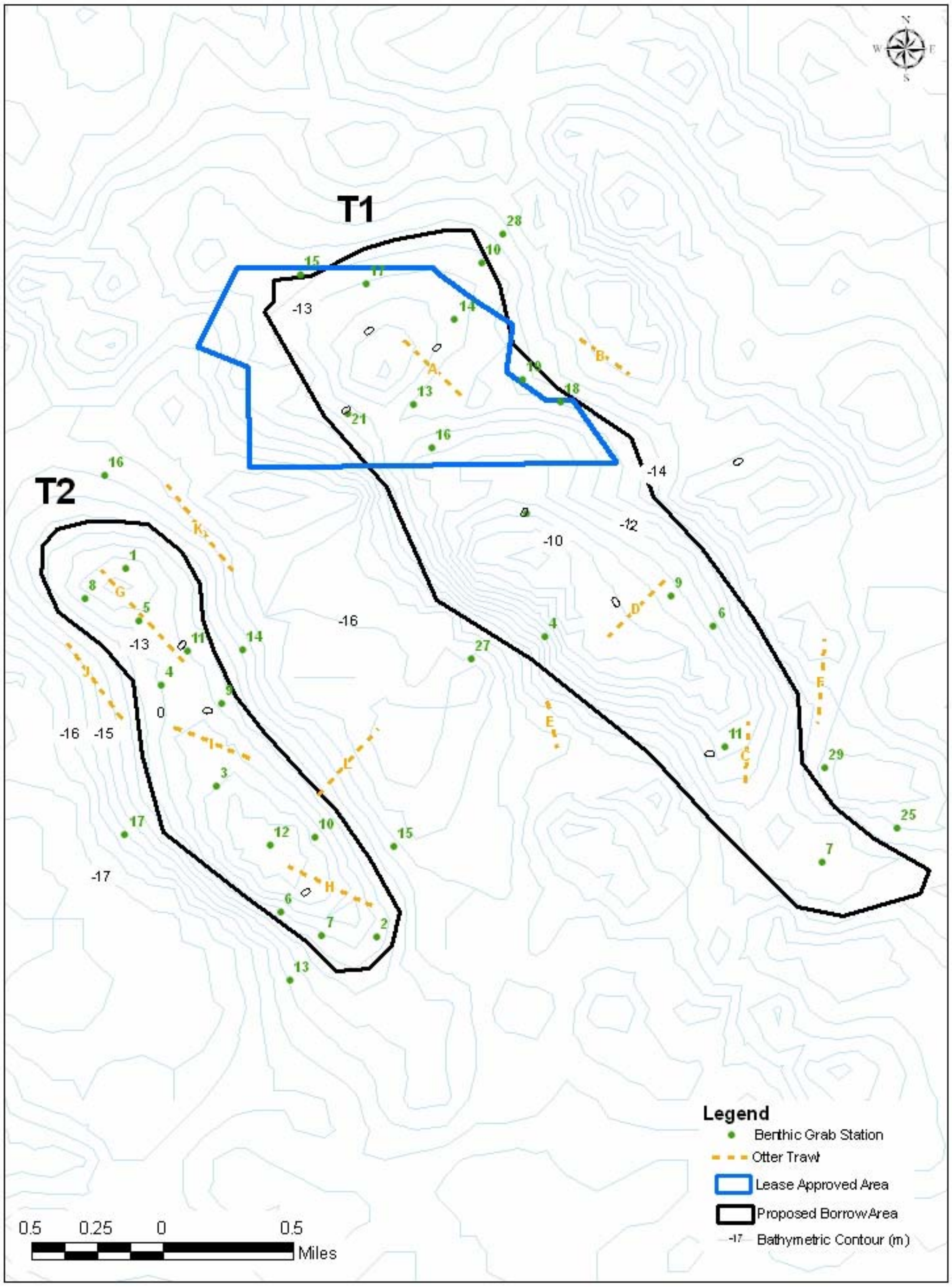


Figure 3-2. Locations of benthic grabs and otter trawls at the T1 and T2 sites, Fall 2005. (The blue polygon represents the area approved in MMS/Collier County lease).

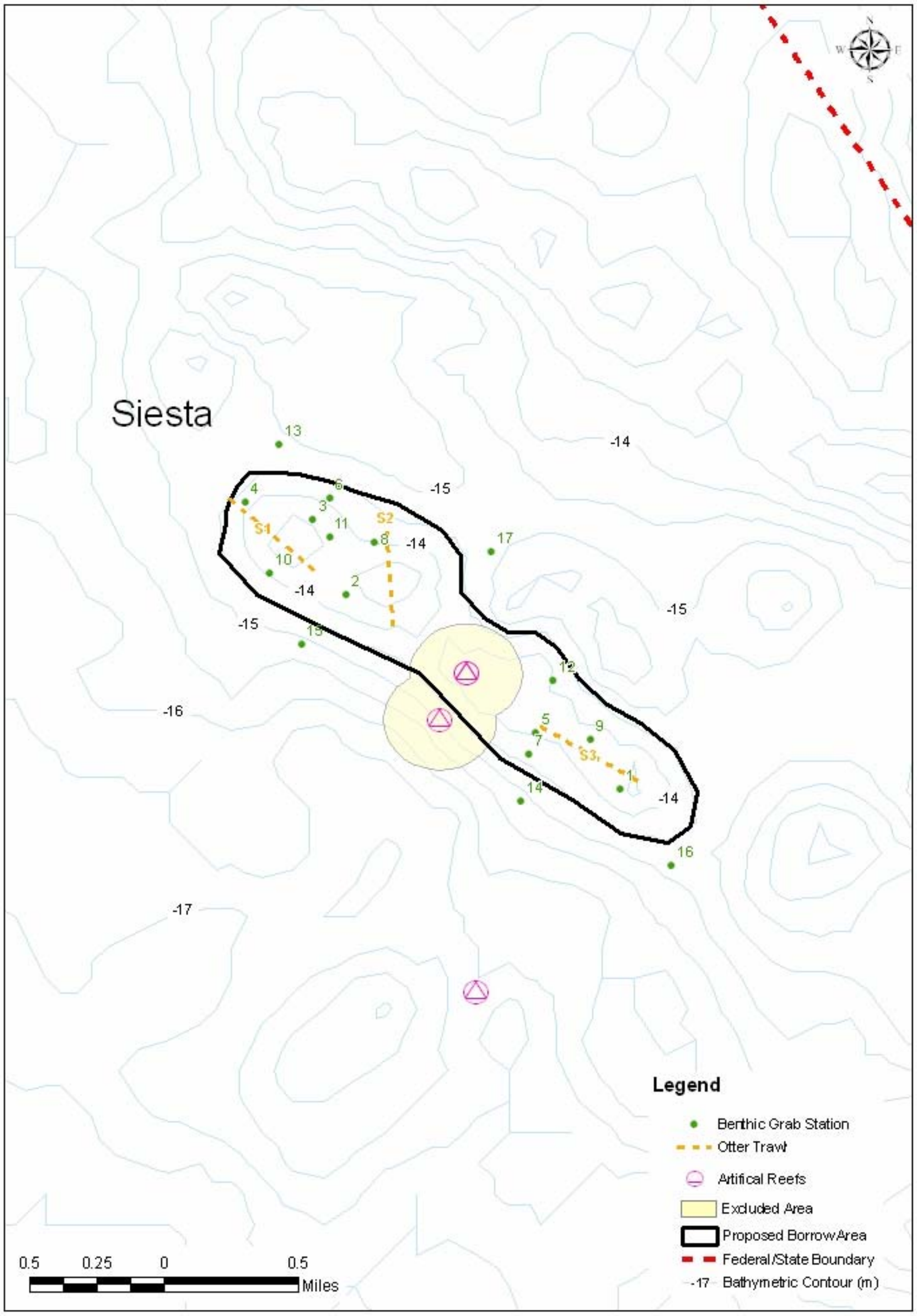


Figure 3-3. Locations of benthic grabs and otter trawls at the Siesta Shoal site, Spring 2006.

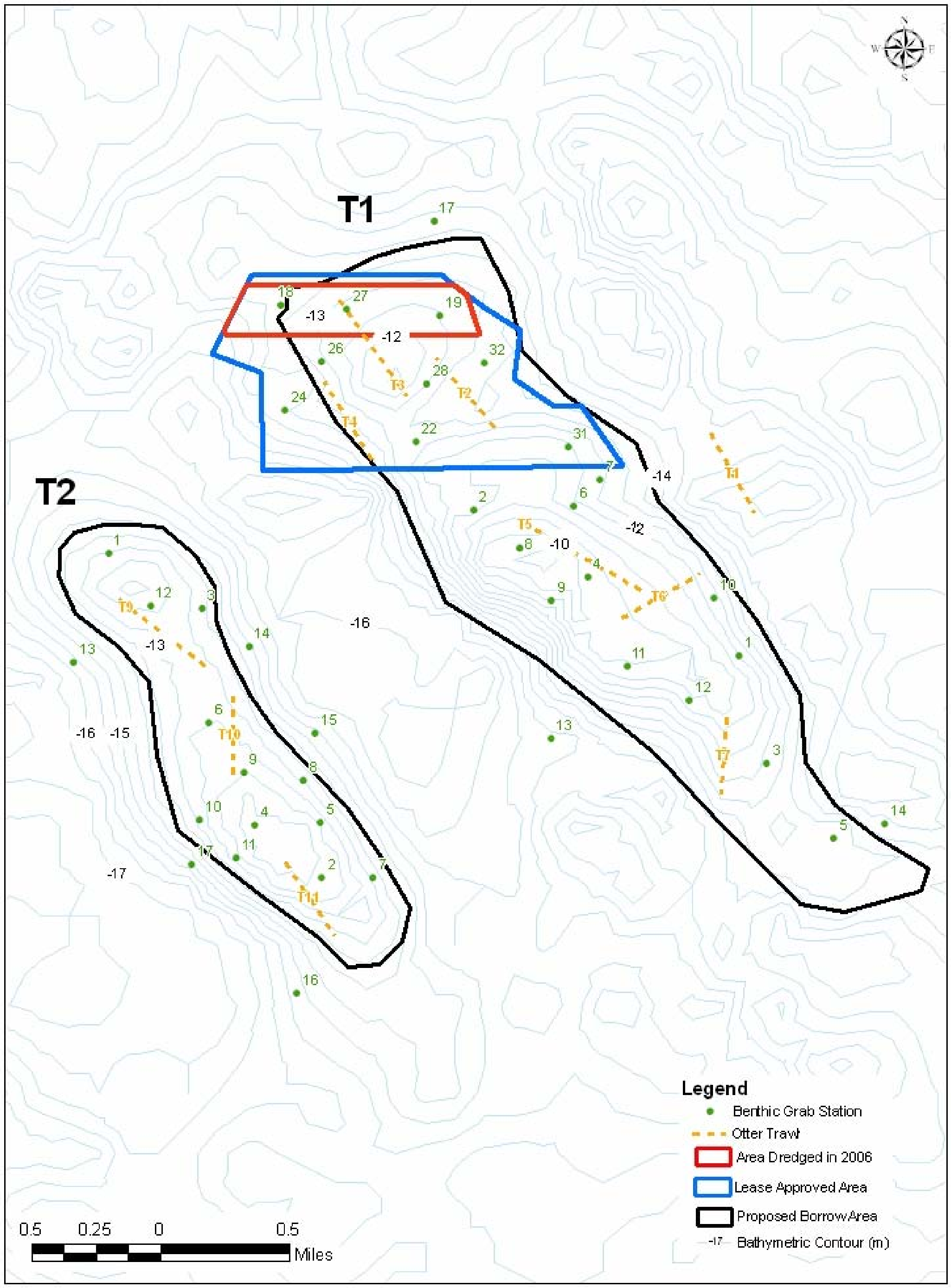


Figure 3-4. Locations of benthic grabs and otter trawls at the T1 and T2 sites, Spring 2006.
(The blue polygon represents the area approved for dredging in the MMS/Collier County lease. The red polygon represents the actual dredged area based on post-dredge survey from CPE 2006).

3.2.1 Water Column

A continuous profile of salinity, temperature, dissolved oxygen, and chlorophyll-a throughout the water column was collected using a Sea-Bird CTD (model SBE-19 equipped with a Sea-Bird SBE23 DO sensor and SCUFA fluorometer) at selected benthic grab stations within the three study areas. Three CTD casts were performed within each study area, except for T2 in June 2006, when six CTD casts were made. At Siesta Shoal during the fall (2005) sampling event, CTD casts were made at benthic grab stations 3, 9, and 12 and during the spring (2006) sampling event casts were made at stations 1, 3, and 12. At the T1 Shoal during the fall (2005) sampling event, CTD casts were made at benthic grab stations 1, 11, and 21 and during the spring (2006) sampling event casts were made at stations 5, 6, 12, 22, 26, and 32. At the T2 Shoal during the fall (2005) sampling event, CTD casts were made at benthic grab stations 1, 6, and 9 and during the spring (2006) sampling event casts were made at stations 7, 10, and 12. The data were plotted using the program SEASAVE V7, displaying the downcasts only. The locations of benthic stations where water quality profiles were conducted are presented in Appendix B.

3.2.2 Sediments

3.2.2.1 Field grab samples and lab methods

A 5-cm diameter acrylic core was used to collect surface sediment subsample from each grab station after any meiofaunal subsample and prior to processing/sieving for macrofauna. Each sediment sample was placed into pre-labeled plastic self-locking bags with the station number and date. Sediment subsamples were transported to the laboratory for grain size analysis and testing for percent organic and carbonate content. S.E.A. conducted the grain size analysis of sediment samples following American Standard Testing Materials (ASTM) standard D-422 for mechanical (sieve) particle size analysis of soils, which is the standard accepted by the USACOE Jacksonville District and the Florida Department of Environmental Protection (FDEP).

Each sediment subsample was split into two sub-samples if there was an adequate amount of material. One of the two sub-samples was used to perform the various sediment analyses and the second sub-sample was archived. For bulk fine (silt and clay fraction) and coarse contents the ASTM D1140 and the Wentworth procedures of determining percent fine fraction were followed. A sub-sample of approximately 30 grams was wet-sieved through a #230 screen (.074 mm opening) to remove the fine fraction. The coarse fraction remaining on the #230 screen was dried and mechanically sieved. Any residual fine material passing through the #230 screen was weighed and the weight was added to the fine fraction calculations. The percent fine sediment passing through the #200 sieve was calculated and reported as well.

Grain-size analysis of the sand fraction remaining on the #230 sieve after wet sieving for the fine fraction content was accomplished using mechanical methods described under ASTM. The sieving technique consists of a set of nested screens that divide sediments into class sizes at 1/2 phi-intervals. Intervals between classes are arithmetic on the phi scale and logarithmic on the millimeter scale. Weight retained on each sieve is used to compute grain-size distribution in terms of weight percent of sample in each size class. Weights were recorded and digitized in gINT ™6.0 geotechnical software.

The percent organic content of each sample was determined using ASTM D2974, which is a gravimetric analysis based on loss on ignition. Sub-samples were air-dried, weighed with a precision electronic balance, and then ignited in a high temperature oven for approximately 8 hours. Data were recorded and digitized in gINT ™ software. After cooling, the sample was re-weighed to determine loss of weight. The sample was returned to the oven for carbonate analysis described in the next paragraph. These data were used to compute the approximate amount of organic carbon not contained in the carbonate (shell fraction).

A high temperature burn method was used to determine the percent calcium carbonate content (shells and shell fragments) of marine sediments. This is a method described in standard texts on sedimentologic analysis and involves igniting a pre-weighed 10 gram sample at approximately 1100° C for 8 hours. During ignition, the carbonate (calcite) crystal lattice is broken, carbon dioxide released, and only the calcium atoms remain. Thus, the weight percent carbonate can be easily calculated knowing the atomic weights of the atoms forming the calcite lattice.

3.2.2.2 Analytical methods

The grain-size distribution of samples processed by mechanical sieving was analyzed using the method of moments and according to graphic methods described by Folk (1974). The moments method is similar to the computation of the center of the mass or moments of inertia described in any elementary calculus text. The first and second moments provide the arithmetic mean grain-size and variance (standard deviation) in phi units, which are equivalent to the geometric mean and standard deviation in millimeters. Higher moments provide the basis for computing skewness and kurtosis of the grain-size distribution, which are measures of deviation from a normal (Gaussian) grain-size distribution. The median grain-size is determined as the size corresponding to the 50 percentile. The modal grain-size is the size that occurs with highest frequency, and can be determined visually from a frequency distribution plot.

Presentation of grain-size analysis for each sample includes a plot of frequency vs. grain-size and a plot of cumulative frequency vs. grain-size on USACOE engineering form 2087. The plot includes data on percentages of fines (#200 and #230), carbonate, organics, and classification. All samples were plotted on Form 2087 (see Appendix C1).

A table was generated in Excel ™ using gINT 6.0™ geotechnical software for each sample processed by mechanical sieving. Reported in the table were sieve size, phi size, mesh size in millimeters, weight of sediment retained (g), cumulative percent retained and cumulative percent passing (see Appendix C1).

3.2.3 Benthos

3.2.3.1 Field Sample Collection

Samples were collected at pre-selected positions. Exact sample station coordinates were recorded. Each Smith-McIntyre grab sample was visually inspected to ensure that the sample collected was undisturbed and an adequate volume of sediment was collected. If the grab volume was, less than 50%, it was rejected and another grab was collected. Additionally, disturbed samples (e.g., sediment surface disrupted) were discarded. Photographs were taken of sample retrieval and processing on deck. Selected photographs are provided in Appendix B.

Seventeen benthic grabs were taken at both the Siesta and T2 study sites during the 2005 and 2006 surveys. Twenty grabs were taken at site T1 during the 2005 survey; twenty-five grabs were taken during the second 2006 survey in an attempt to collect samples within an area that had been recently dredged (February – May 2006).

3.2.3.2 Laboratory Processing

Macrofaunal Samples

Individual grab samples were handled and processed separately. After subsamples were collected, the remaining sediment collected in the grab was emptied into 5 gallon tubs. The contents were then transferred to a 0.5 mm sieve bucket/tray. The bottom of the sieve bucket/tray was immersed in an approximate 30 gallon trash can filled with ambient seawater, shaken, and swirled to suspend the larger material, allowing fine sands, silts and clays to pass through the sieve screen. The residual material on the sieve screen was washed into 0.5 or 1 gallon sample jars pre-labeled with permanent ink on the outside and mylar label on the inside. After sieving, the screen was inspected for any organisms not washed into the sample container. Such organisms were removed with dissecting forceps and placed into the appropriate sample jar. Samples were fixed in a 10% buffered ambient seawater-formalin solution. Sodium borate was used as a buffer. A 1% solution of rose bengal stain was premixed and added to the formalin solution.

Samples were transferred from formalin to 70% ethanol within approximately 2 weeks of collection. Samples were initially sorted from the sediment matrix and identified into four major groups – polychaetes, crustaceans, molluscs, and other/miscellaneous. Organisms were placed into separate vials representing the 4 groups and containing 70% ethanol. Subsequently, all specimens were identified to the lowest practical taxonomic level. All species counts were recorded on Lab Taxonomy Data Sheets.

A reference collection of all macrobenthic species was established. Up to 5 representative specimens of each taxon were placed in the voucher collection; macrofauna were placed in labeled vials and archived in 70% ethyl alcohol with glycerol. When specimens were removed from the samples for the reference collection, it was noted on the appropriate Lab Data Sheet. Attempts were made to include a variety of size classes for each species.

3.2.3.3 Epifauna Camera Sled

During the first survey in October 2005, an epifauna camera sled was towed on predetermined transects throughout the study areas. The camera was a Simrad OE Model 9030 Underwater Color TV System with integrated light and DVD recording. The sled was towed at approximately 2 – 3 knots and approximately 3 ft off the bottom.

A separate DVD recording with a date and time stamp was made of each transect. Although the image does not contain position information, the vessel's position was logged and time stamped by the GPS receiver, and was synchronized with the video time stamp, allowing a relative measure of where the particular image originated.

Three camera transects were conducted at T1; five transects were conducted at T2; and four transects were conducted at Siesta Shoal. The length of camera transects at each study area were as follows: 2,102 m at T1; 11,208 m at T2; and 4,624 m at Siesta Shoal. A total of 17,934 meters (11.14 miles) of camera transects were collected. The locations of the epifauna camera transects are shown in Figures 3-5a and 3-5b.

Qualitative observations of the transect recordings were made and lists of observed epifauna and fish were compiled. There were occasional areas of poor visibility within some transects.

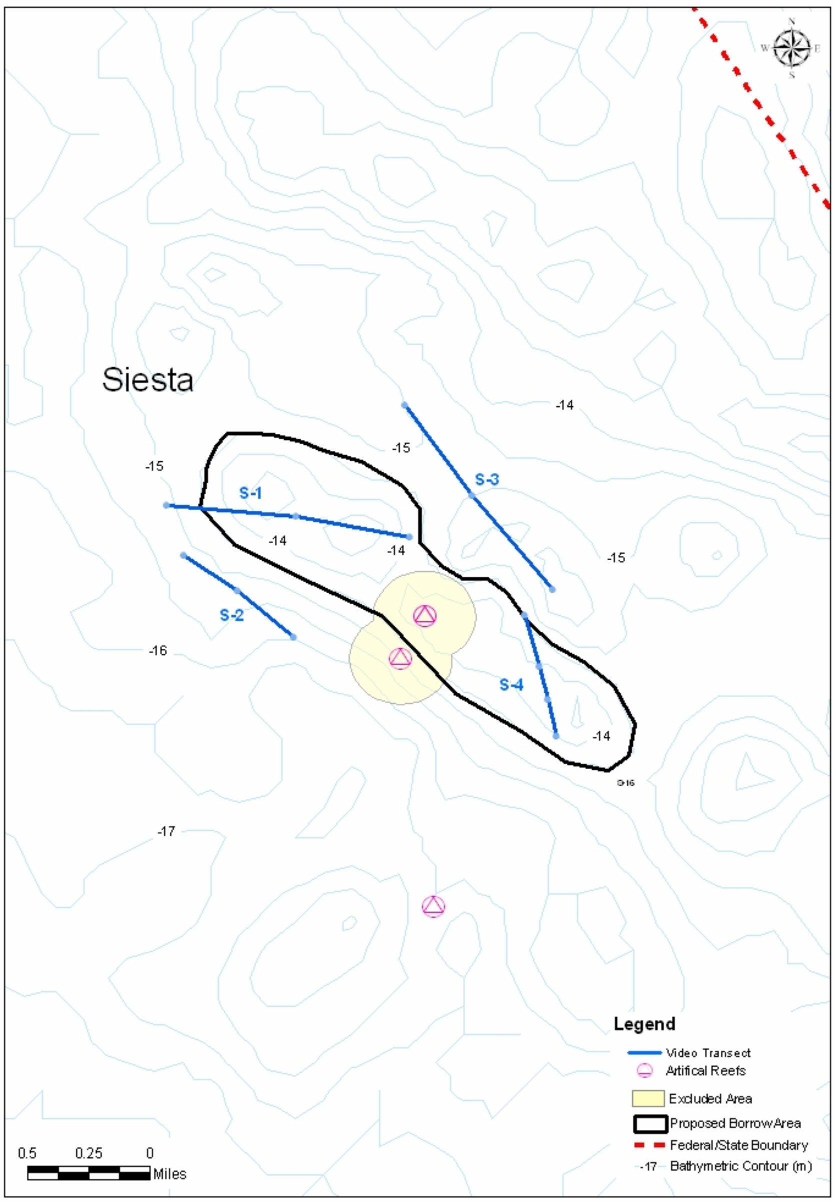


Figure 3-5a. Locations of epifauna camera sled transects on Siesta Shoal.

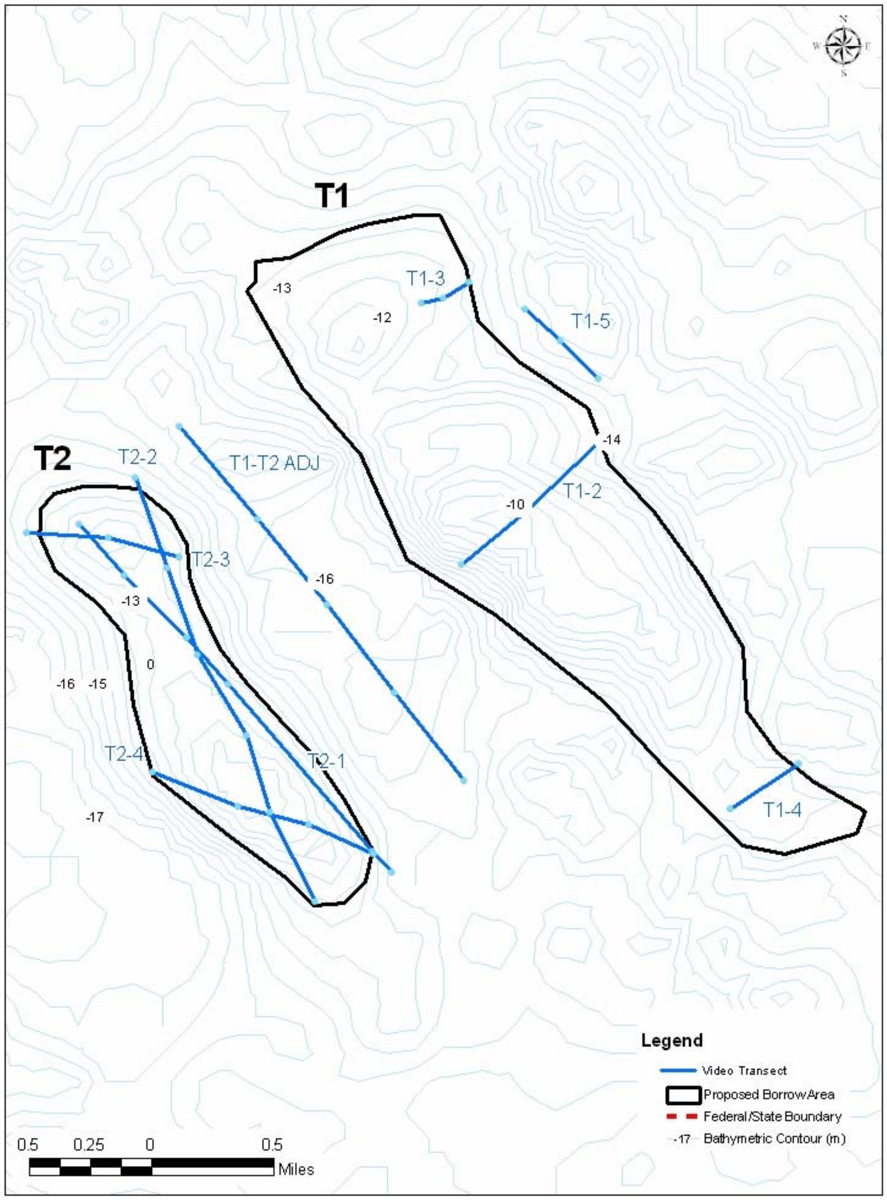


Figure 3-5b. Locations of epifauna camera sled transects on T1 and T2.

3.2.3.3 Statistical Analyses

Summary statistics including number of taxa, number of individuals, density, diversity (*H'*), evenness (*J'*), and species richness (*D*) were calculated for each sample station. Diversity (*H'*), also known as Shannon's index (Pielou, 1966), was calculated as follows:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

where *S* is the number of taxa in the sample, *i* is the *i*th taxa in the sample, and *Pi* is the number of individuals of the *i*th taxa divided by (N) the total number of individuals in the sample.

Evenness (*J'*) was calculated with Pielou's (1966) index of evenness:

$$J' = \frac{H'}{\ln(S)}$$

where *H'* is Shannon's index as calculated above and *S* is the total number of taxa in a sample.

Species richness (D) was calculated by Margalef's index:

$$D = \frac{(S - 1)}{\ln(N)}$$

where *S* is the total number of sample taxa and N is the number of individuals in the sample.

Spatial and temporal patterns in infaunal assemblages were examined with cluster analysis. Cluster analyses were performed on similarity matrices constructed from raw data matrices consisting of taxa and samples (station – survey). Cluster analysis excluded those taxa that were not identified to at least family-level. Of these taxa, only those contributing at least 0.1% of the total abundance were included. Raw counts of each individual infaunal taxon in a sample (n) were transformed with the log10 (n+1) transformation prior to similarity analysis. Both normal (stations) and inverse (taxa) similarity matrices were generated using the Bray-Curtis index that was calculated using the following formula:

$$B_{jk} = \frac{2\sum_i \min(x_{ij}, x_{ik})}{\sum_i (x_{ij} + x_{ik})}$$

where *Bjk* (for normal analysis) is the similarity between samples *j* and *k*; *xij* and *xik* are the abundances of species, *i* in samples *j* and *k*. *B* ranges from 0.0 when two samples have no species in common to 1.0 when the distribution of individuals among species is identical between samples. For inverse analysis, the *Bjk* is the similarity between species *j* and *k*; *xij* and *xik* are the abundances of species *j* and *k* in sample *i*. Normal and inverse similarity matrices were clustered using the group averaging method of clustering (Boesch, 1973). Multi-dimensional scaling was used to determine the relationship between station sediment parameters (mean grain size, percent fines, and percent carbonate) and station groups identified by normal cluster analysis as being similar with respect to species composition and relative abundance.

3.2.4 Fisheries Methods: Fishes, Ichthyoplankton and Fisherman Survey

Trawl Collections

Otter trawls were employed to characterize the demersal fish fauna within and adjacent to each proposed sand borrow site. The original sampling protocol for both survey periods called for three trawls to be conducted along randomly selected pre-designated transects both inside and outside T1, T2, and Siesta Shoals (18 total tows per survey). Actual sampling deviated from the planned protocol because limestone hardbottom substrates were encountered outside Siesta Shoal (causing considerable net damage) permitting the completion of only a single trawl during the fall 2005 survey and none during the spring 2006 survey. Similarly, attempts to trawl outside T 2 during the spring 2006 survey also resulted in net damage; limiting trawls inside this borrow area. Consequently, an additional trawl was added outside T1; hardbottom was also encountered here but the catch was recovered intact.

The otter trawl possessed a 7.6 m headrope with 2.5 cm stretched mesh and heavy cod end chafing gear. A ¼" fine mesh inner liner was sewn inside to enable the capture of small fishes and invertebrates. Tows were made at 2.5 knots for 10 minutes with precise trawl distances calculated from GPS locations. Positions of the starting and ending points of each trawl are provided in Appendix B. Following net retrieval of each successful trawl, the catch of fishes and macroinvertebrates was sorted to the lowest practical identifiable taxon and up to 25 fishes per species were measured to the nearest mm standard length (SL). Individuals that could not be identified on deck were frozen for later species confirmation in the laboratory. Specimens of various demersal fish species were also retained for gut content analyses (see below). Trawl catches were standardized to densities (individuals per hectare) by dividing captures into the area swept during each tow. Area swept (ha) was calculated by multiplying the distance trawled (m) by headrope width (m) and dividing this product by 10,000 m^2/hectare.

Spatiotemporal differences in the otter trawl fish and macroinvertebrate species assemblage was explored using non-metric multidimensional scaling (MDS). Densities (individuals per ha) of replicate samples from each site and time combination were averaged and fourth-root transformed, a practice that "downweights" numerically dominant species, allowing less abundant taxa to also contribute to sample discrimination (Thorne et al., 1999). A sample similarity matrix was then constructed using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957) and MDS was then employed to generate a low-dimensional ordination (map) of sample similarities across sites and cruises where interpoint distances are proportional to overall faunal similarity (Clarke, 1993). While a small number of juvenile fishes and invertebrates were not identified to species level, they were included in this analysis at genus or family level since ordination with them removed from the dataset yielded similar results. Sites where hardbottom substrates prohibited trawl collections (Outside Siesta Shoals fall 2005 and spring 2006, and Outside T2 spring 2006 -2 only) were not included in this analysis.

Feeding Habits

To identify the trophic relationships between the local invertebrate fauna and abundant demersal fish taxa, fish specimens from several species retained from trawl samples were returned to the laboratory where viscera were removed from up to ten individuals per taxa from each collection. All stomachs were then preserved in 70% isopropyl alcohol pending further analysis. Feeding analyses were not conducted on intestinal contents as prey items here were in generally too digested to be identified. The first step in processing was to record semi-quantitative assessments of (1) stomach fullness, and (2) state of digestion of prey items as:

(1) Fullness Index (FI), where
0 = empty;
1 < 1/3 full;
2 = 1/3-2/3 full;
3 > 2/3 full;
4 = distended, rugae (inner folds of stomach lining) fully flattened;

(2) Digestion Index (DI), where
0 = fully digested, unrecognizable;
1 = only hard parts and major structures recognizable, may be identifiable to group;
2 = easily identifiable to major group;
3 = fully identifiable to species

Prey items in stomachs were then identified to the lowest practical taxon, enumerated, and wet weights were recorded. In certain cases, identifications were based on the presence of structures such as crustacean eyes, which digest more slowly than other portions of the body. Because the relative dietary value of different prey is a function of prey size, mass, and abundance, these data were then used to calculate an Index of Relative Importance (IRI) for each prey item (i) for each species examined:

$$IRI_i = O_i * (\%W_i + \%N_i)\text{, where}$$

O_i = frequency of occurrence of prey (i) among all stomachs in the sample;
$\%W_i$ = proportion of weight of prey (i) to the total weight of all prey;
$\%N_i$ = proportion of numerical abundance of prey (i) to the total numbers of all prey.

Plankton Tows

As a means of characterizing fish larvae present in the water column over potential sand borrow areas, three replicate nocturnal neuston (surface) and ichthyoplankton (sub-surface) tows were scheduled within each proposed site (18 total tows per cruise). Positions of the starting and ending points of plankton and neuston tows are provided in Appendix B. During the fall 2005 survey, surface samples were taken with a 1 m wide x 0.3 m deep rectangular neuston net towed at 1 m/sec for 10 minutes just below the air-water interface. Sub-surface tows were conducted with a 1 m conical plankton net towed in a stepped oblique fashion, five minutes each at 3.0 m and 6.1 m depths. Mesh width for both nets was 500 µm. Poor weather during one day of the fall 2005 survey limited sampling at T2 (12 total samples). The sampling protocol for the spring 2006 survey was similar except that a 1 m conical net was employed for both neuston and sub-surface tows. Water volume filtered during each tow was calculated with a General Oceanics 2030 flow meter. All samples were fixed in 10% buffered formalin in the field and subsequently transferred to 70% ethanol prior to sorting. In the laboratory, fish larvae were removed from samples, identified to the lowest practical taxon under a dissecting microscope, and measured to the nearest mm notocord length (NL) for preflexion larvae or SL for flexion/postflexion larvae. Larval density (individuals per 1000 m^3) was then generated from flow meter data.

Fishermen Surveys

In May and June 2006, interviews were conducted at known ports of entry for fishermen off the southwest coast of Florida in Tampa Bay and in Sarasota and Lee Counties. Over approximately a one-week period boat captains, charter fishing guides, and owners of boat supply, bait and tackle stores, and dive shops were interviewed to obtain information about fishing practices on and/or near the MMS study sites and their perceptions of dredging impacts to the fishing industry. During interviews information was gathered to identify the categories of fishermen (commercial or recreational), primary target fish species, target habitat (hard bottom, sand bottom, artificial reef, and/or open water), fishing location on study sites and/or within 5 miles, and fisherman concerns about dredging. A blank questionnaire is provided in Appendix B.

3.2.5 Marine Mammals, Sea Turtles and Sea Birds

Two survey methods were employed for protected marine species data collection:

1) Visual detection with photographic documentation
2) Acoustic detection with spectral analysis documentation

Two trained visual observers were deployed during daylight hours to document marine mammals, sea turtles, and sea birds. Equipment for visual observations included a Canon S1 digital camera, 8X50 binoculars, notebook, and polarized sunglasses. Visual observations for protected species occurred from sunrise until sunset while sediment sampling was being conducted. During bad weather, observations occurred from the deck. In good weather, observations were conducted above the wheelhouse to achieve a 360˚ view. Short breaks in observations occurred during Passive Acoustic Monitoring (PAM) deployment, when only one observer was working.

Observation data was recorded at least every 15 minutes. Start and stop times were noted on Observer Logs –Data Sheets Protected Species Recording Form - *Location and Effort Data*. Protected species sea turtles and marine mammals were recorded on the *Record of Sighting* Form for species documentation (see Appendix B). Digital still imagery was collected when possible to document sighting and to identify individuals. Datasheets were filed for each field session.

PAM occurred on the same days as the visual surveys. Hydrophones were deployed during daylight hours. The PAM system includes hydrophones from Cetacean Research, a Dynamic Signal Acquisition (DSA) system from Sound Technology Corporation, and a mobile computer with several acoustic analysis programs. The hydrophones from Cetacean Research are omnidirectional on a plane with a Frequency Response of 15 Hz to 250 kHz. The software programs used to analyze the data in real-time are Whistle, from the IFAW and Ishmael, from NOAA.

A digital sound file was compiled for each survey within the spectral analysis program, *Ishmael* (David Mellinger, NOAA). The program was set to record specific energy contents or frequencies and to annotate those specific recordings to save onto a PC hard drive. The specific energy contents or frequencies that trigger annotation where never encountered. Recordings were saved on a USB mass storage device and reviewed. Recordings of species or possible species of interest were filed separately. All recordings are time and date stamped. An associated acoustic monitoring form was filled out for each monitoring session. Sessions were assigned unique numbers under the following format: Year_Month_Day_00:00 start – 00:00 end. GPS locations were taken at the start and finish of any recording sessions and recorded on the data sheets. Following collection and post processing, all data were recorded in Microsoft Access databases. Acoustic observation sessions were recorded on Acoustic data sheets, presented in Appendix B.

3.3 Results of Data Analysis from Fall 2005 and Spring 2006 Field Events

3.3.1 Water Column

At Siesta Shoal, the fall (2005) water temperatures were approximately 28°C, with temperatures slightly warmer (less than half of a degree) at the surface. Dissolved oxygen concentrations were approximately 6.5 mg/L and were uniform throughout the water column. Salinities were approximately 35.2 PSU throughout the water column. Chlorophyll fluorescence was approximately 6.6 µg/L throughout the water column. In the spring (2006), water temperatures were approximately 27°C, with temperatures slightly warmer at the surface. Dissolved oxygen concentrations were approximately 6.5 mg/L and were uniform throughout the water column. Salinities were approximately 35.8 PSU throughout the water column. Chlorophyll fluorescence increased from approximately 1.5 µg/L at the surface to 2.4 µg/L at the bottom. Figure 3-6 presents a water quality profile for Siesta station 12, taken during June of 2006. All of the water quality profiles taken during the study are in Appendix B.

At the T1 Shoal, the fall (2005) water temperatures were approximately 28.5°C, with temperatures very slightly warmer (less than half of a degree) at the surface. Dissolved oxygen concentrations were approximately 6.4 mg/L and were uniform throughout the water column. Salinities were approximately 35.3 PSU throughout the water column. Chlorophyll fluorescence decreased from approximately 8 µg/L at the surface to 6 µg/L at the bottom. In the spring (2006), water temperatures were approximately 28°C, but were generally up to a degree warmer at the surface. Dissolved oxygen concentrations were approximately 6.4 mg/L, and were uniform throughout the water column. Salinities were approximately 36 PSU throughout the water column. Chlorophyll fluorescence was approximately 1 to 1.5 µg/L and was relatively uniform throughout the water column.

At the T2 Shoal, the fall (2005) water temperatures were approximately 28.4°C, with temperatures very slightly warmer (less than half of a degree) at the surface. Dissolved oxygen concentrations were approximately 6.4 mg/L and were uniform throughout the water column. Salinities were approximately 35.2 PSU throughout the water column. Chlorophyll fluorescence decreased from approximately 10 µg/L at the surface to 5 µg/L at the bottom. In the spring (2006), water temperatures were approximately 27.7°C, but were up to half a degree warmer at the surface. Dissolved oxygen concentrations were approximately 6.4 mg/L, and were uniform throughout the water column. Salinities were approximately 36.2 PSU throughout the water column. Chlorophyll fluorescence ranged from 1 to 1.6 µg/L with higher values near the bottom.

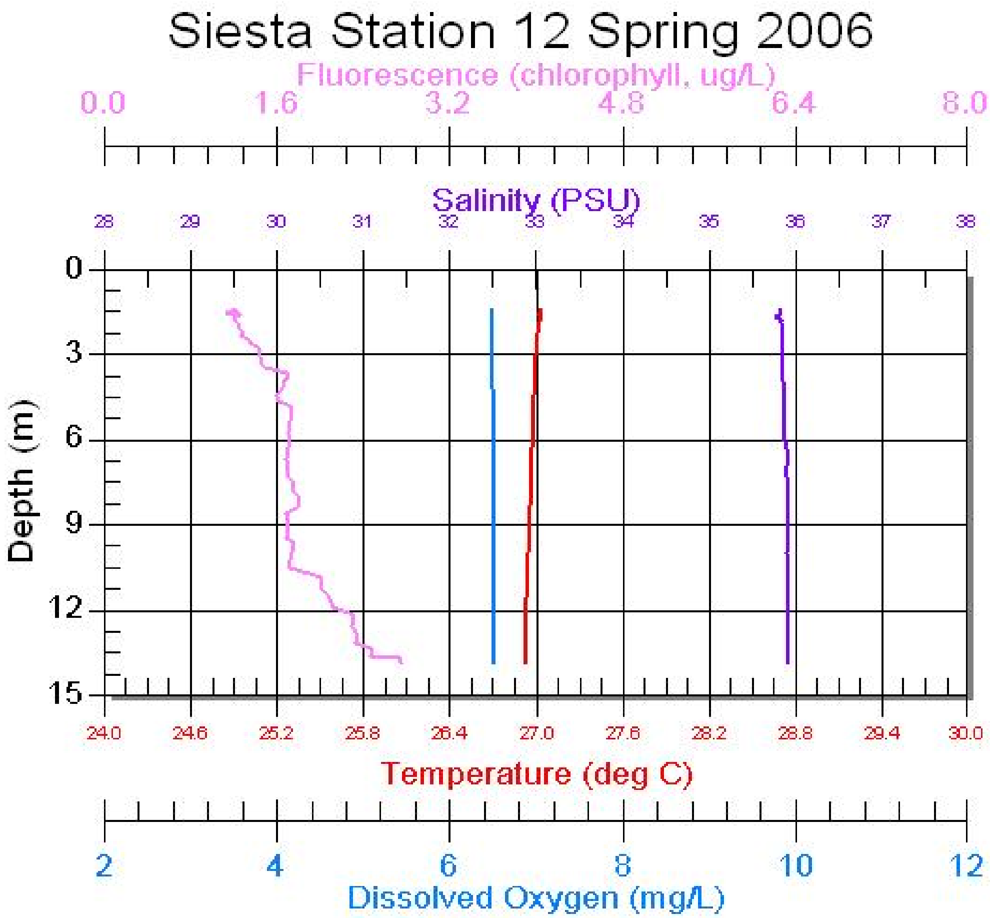


Figure 3-6. Water quality profile for Siesta station 12, taken during June 2006.

3.3.2 Sediments

One hundred and fifteen (115) sediment samples collected during the two field events were processed for grain size distribution, percent carbonate, and organic content. Presentation of grain-size analysis for each sample is shown in a plot of frequency vs. grain-size and a plot of cumulative frequency vs. grain-size on USACOE engineering Form 2087 (Appendix C). The plot includes data on percentages of fines (#200 and #230), carbonate, organics, and classification according to the Unified Soils Classification System (USCS). Tables of grain size data provide the weight percentage by size class and cumulative weight percentage retained on each sieve as the sediment passes through the stack of sieves. Appendix C contains a plot and data sheet results for each sample from both events.

Analysis of fifty-five (55) sediment samples collected from all three study sites during the fall (2005) field event shows that surficial sands ranged from fine well sorted sand having a Unified Soils Classification (USCS) of SP to few silty samples designated as SM in the USCS having high percentages of coarse carbonate in the form of shell fragments and whole shells. The percentages of sediment in the silt and clay range contained in the samples ranged from 0% to 17.1%. The percent of carbonate material ranged from 12.7% to 95.2% and correlated well with mean and median grain size of the samples. The percent of organic material ranged from 0.53% to 26.7%. Similar ranges of textural properties were found in sixty

(60) samples collected during the spring (2006) field event. However, from the T1 Shoal, the percent organic matter in samples collected in 2005 was notably higher than the percent organic matter present in the samples from the 2006 survey. Because the T1 shoal was dredged in late 2005 and approximately 600,000 cubic meters of beach quality sand were excavated, the dredging activity may have stripped much of the organic matter from the surface sediment layer of the T1 Shoal.

Based on sample textural properties and the percent of fine material, most samples were classified using the USCS designation SP indicating that the samples consisted primarily of sandy textures. Those samples having 11% or more fine material passing the #200 sieve (finer that 74 microns) were classified under USCS with the SM designation indicating a silty sand textural composition. The coarser textures were found in samples having either high calcium carbonate content or samples collected from the higher elevations of the shoals. These samples had median and mean grain sizes generally exceeding 0.3 mm and up to a maximum of 0.64 mm. Samples obtained from topographically lower positions on the flanks of the shoals, completely off the shoal structure, or containing lower percentages of carbonate (shells and shell fragments) had average grain sizes less than 0.3mm.

Table 3-1 is a summary of textural and compositional properties found in each shoal recorded from the 2005 and 2006 field surveys. A complete listing of the properties of each sample can be found in Appendix C. Overall the samples from the Siesta Shoal were coarser and contained higher percentages of carbonate material, mostly in the form of coarse shell fragment. None of the samples from the Siesta Shoal 2005 survey had a textural distribution broad enough to be designated with the SW Unified Soils classification. However, one sample from the lower flank of the Siesta Shoal contained enough fine material for it to be classified as silty sand using the USCS SM designation.

Table 3-1. Properties of Texture and Composition

Shoal Name	**Field Event**	**Unified Soils Class**	**Mean (mm)**	**Median (mm)**	**Silt/clay %**	**Carbonate%**	**Organic%**
T1	2005	SP	0.24-0.66	0.22-0.64	0.1-5.0	13-62	6-27
T2	2005	SP	0.26-0.54	0.24-0.48	0.0-5.0	13-32	0.5-14
Siesta	2005	SP, SM	0.09-0.64	0.08-0.58	0.9-17.1	57-95	1.7 - 3.2
T1	2006	SP	0.24-0.60	0.23-0.56	0.08-1.5	12-47	0.6-1.6
T2	2006	SP	0.29-0.54	0.28-0.49	0.01-3.5	12-37	0.6-1.5
Siesta	2006	SP, SM	0.09-0.70	0.08-0.73	0.02-18.9	48-94	1.8 - 3.2

In the 2006 field event, sixty (60) sediment samples were collected and analyzed from all three study sites. Samples from the Siesta Shoal were coarser and included higher carbonate percentages compared to samples from the T1/T2 Shoals. The coarsest textures among all three sites were found at higher elevations of the shoal crest. Finer textures and greater percentages of silts were found at topographically lower elevations on the flanks of the shoals and off the shoal structures. Sediment textures in the borrow cut areas at the north end of the T1 Shoal were found to be similar to the pre-borrow textures sampled in 2005.

The overall results of the spring 2006 sedimentologic analysis were similar to those of the fall 2005 sample results. The surficial samples collected from the Siesta Shoal were generally richer in carbonate and larger in median grain size. This can be seen in Figure 3-7, which compares median grain size to percent carbonate for each shoal area. This comparison clearly separates the samples into two distinct fields. One field of coarser samples represents Siesta Shoal, whereas the other field in the plot represents finer samples having lower carbonate content collected from the T1 and T2 Shoals. The carbonate fraction in the Siesta samples consisted of shell fragments in the medium to coarse sand size range along with a minor fraction of carbonate shell fragments in the fine gravel size range.

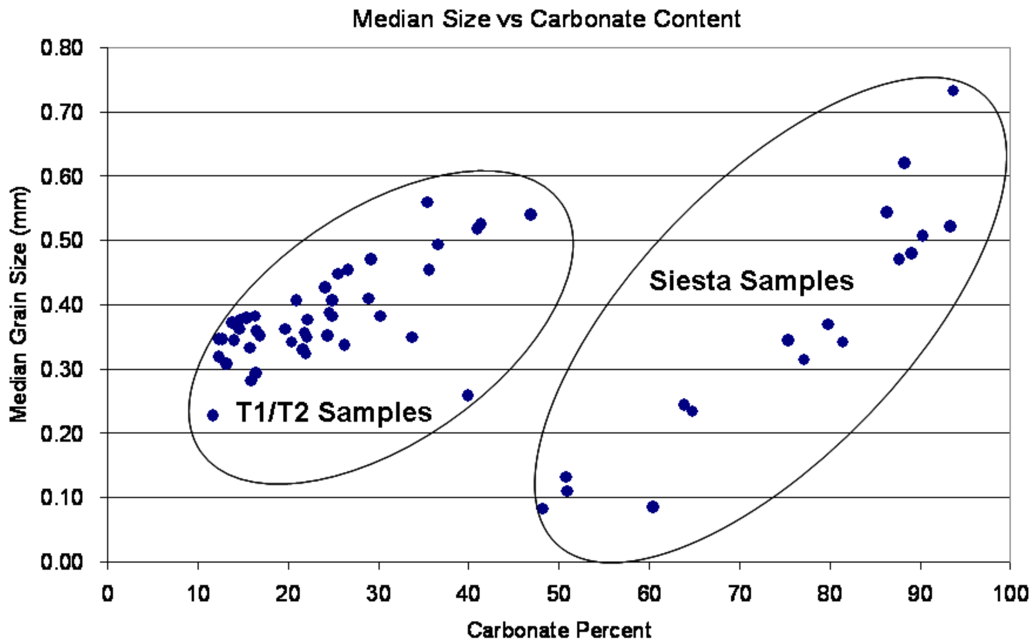
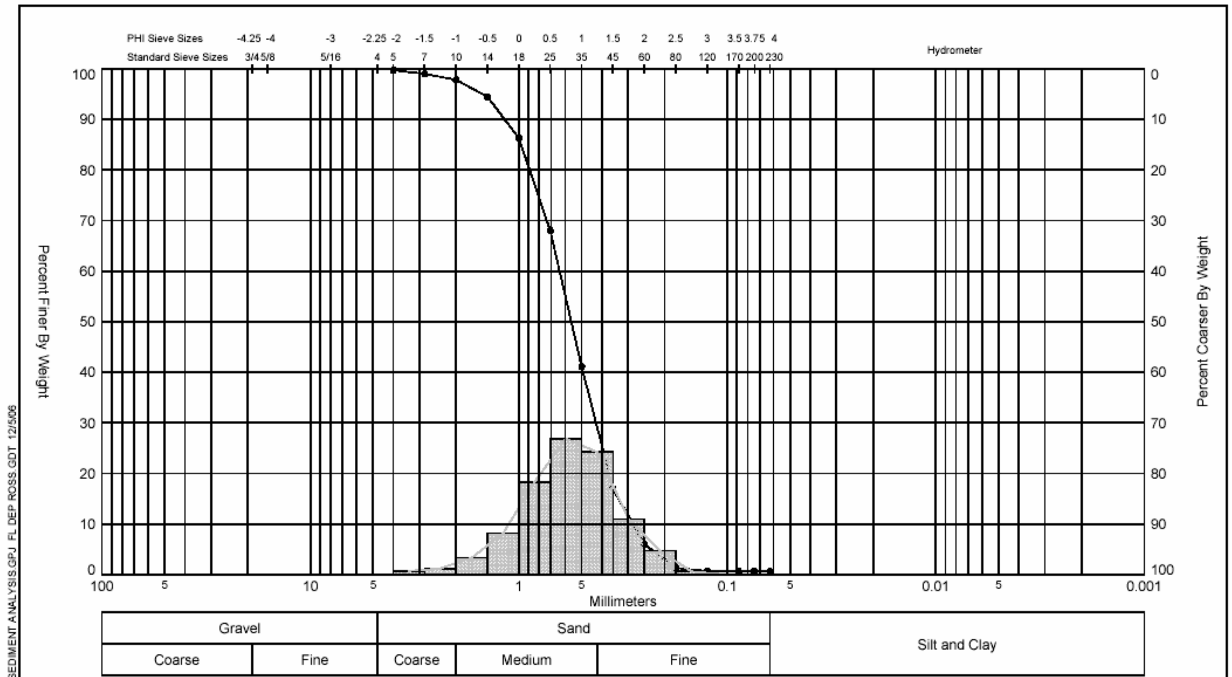


Figure 3-7. 2006 Comparison of median grain size to percent carbonate fraction.

The median grain size of surficial grab samples collected from the T1 and T2 covered a narrower range (0.23 – 0.56 mm) and were finer than the Siesta Shoal samples. Likewise, the carbonate content of the T1 and T2 shoals ranged from about 12 - 47% compared to the 48-94% range for Siesta Shoal. The coarsest textures over the T1/T2 Shoal system were found in the surficial sands at the crest of the shoals. Figure 3-8 shows the grain size frequency distribution of samples W2-T1-03 from the crest of the T1 Shoal. Samples from the flanks and topographically lower areas of the shoals were finer in texture. However, all of the samples contained only minor silt fractions ranging from near zero to about 3.5%. Likewise, the percentage of organic content in the W2 T1/T2 samples was lower compared to the Siesta Shoal samples ranging from about 0.6 to 1.6%.



Sample	Symbol	Elev. (ft)	USCS	% Fines	% Organics	% Carbonates	Median	Mean	Skew	Kurt	Sort
W2-T1-03	—◆—		SP	#200 - 0.65 #230 - 0.65	1.02	35.44	0.84	0.79	-0.31	3.46	0.78

Comments:
Depths and elevations based on measured values

Scientific Environmental Applications
5575 Willoughby Drive
Melbourne, FL 32934
ph 321 254-2708
fax 321 254-2708

Sample Information	
Project Name:	MMS - Field Study 2006 CT-39054
Analysis Date:	09-18-06
Analyzed By:	SEA Inc.
Easting (X, ft):	211,160
Northing (Y, ft):	743,808
Horizontal System:	NAD 1983
Vertical System:	NGVD

Figure 3-8. 2006 Sample W2-T1-03 from the crest of the T1 Shoal. Sample texture is predominantly medium sand, some fine sand and a coarse sand fraction of shell fragments.

Samples W2-T1-18, W2-T1-19, and W2-T1-27 were collected near or within the recent borrow cut at the north end of the T1 Shoal. Compared to the surficial sediments from the central and south end of the T1 shoal, the samples from the borrow area were generally finer and characterized by slightly lower carbonate percentages. Samples collected from the borrow area prior to dredging have textural characteristics similar to those of the post-dredge samples. Thus, the borrow area at the north end of the T1 shoal was selected for vertically uniform lithology, lower percentages of carbonate, and somewhat finer texture compared to other areas of the T1 Shoal. The finer textures in this area are likely to be more compatible with the beach nourishment project approximately 30 miles to the southeast in Collier County.

Median grain size of the Siesta Shoal surficial samples ranges from about 0.1 mm (very fine sand) to 0.7 mm (coarse sand). Figure 3-9 shows the grain size frequency distribution of sample W2-S-08 from the crest of Siesta Shoal. This sample is typical of the coarser carbonate-rich sands found on the surface of this shoal. The carbonate fraction of this sample was more than 93% by weight. Samples having finer textures and silt content more than 10% were found on the topographically lower flanks of Siesta Shoal. Samples W2-S-07 and W2-S-16 listed in Appendix C are typical of this type of surficial sediment texture. The percentage of organic matter in the Siesta Shoal samples ranged from approximately 1.8 to 3.2%.

Samples having coarser textures generally had slightly higher content of total organic carbon compared with samples of finer texture.

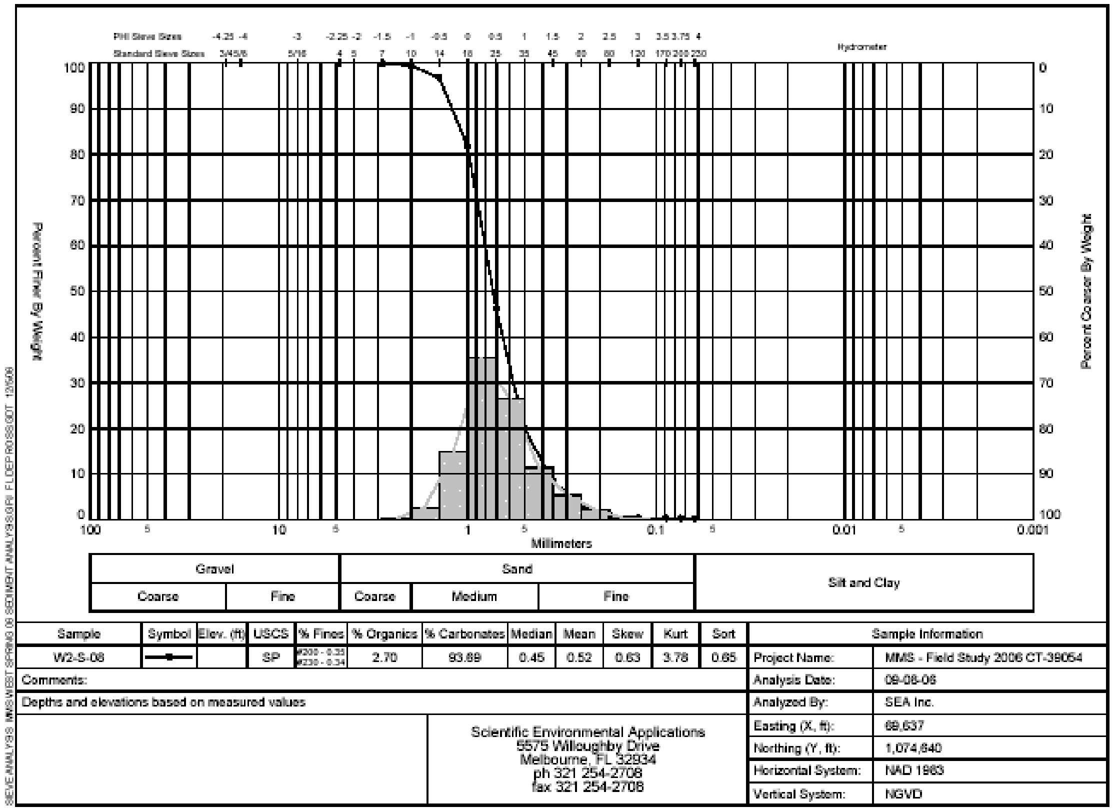


Figure 3-9 Grain size frequency distribution of June 2006 Sample W2-S-08 from the crest of Siesta Shoal. Dominant texture is in the medium sand range compared to the fine sand of samples off the shoal or from the lower flank areas.

3.3.3 Benthos

A taxonomic listing of infauna collected in bottom grabs during the October 2005 and June 2006 surveys is presented in Appendix B. Over both surveys, 65,179 individuals were collected, representing 378 taxa in 11 separate phyla. Most taxa collected were crustaceans (146 taxa), followed by polychaetes (132 taxa), and gastropod (41) and bivalve (32) molluscs. Overall abundance was markedly dissimilar across surveys. Grab samples yielded 13,257 individuals in October and 51,922 in June. One hundred and sixty two taxa (42.7% of total) were common to both surveys. There were 154 taxa restricted to the June survey, and the October survey included 60 taxa not found in June samples. The HAB in the late summer/fall of 2005 is the likely cause for the lower abundance and number of taxa in the October 2005 survey.

Annelids of the genus *Prionospio* were numerically dominant in the grabs, representing 22% of all infauna censused over both surveys. Due to the difficulty in confidently identifying all individuals of *Prionospio* to species (i.e., *Prionospio fallax, Prionospio cristata, Prionosio steenstrupi*) due to the large number of early settlement stages and damaged individuals, we aggregated all *Prionospio* individuals into *Prionospio* spp. The “Other” taxa that were among the top 10 numerical dominants during both the

October and June surveys included the gastropod *Caecum johnsoni*, the hemichordate *Branchiostoma floridae*, the polychaetes *Spio pettiboneae* and *Travisia hobsonae*, the bivalve *Semele nuculoides*, and Sipuncula (LPIL).

Table 3-2 lists the numerically dominant infaunal taxa sampled from each of the borrow sites and overall for the October 2005 and June 2006 surveys. The numerically dominant taxa collected during the October survey was *Spio pettianeae* (15.3% of all individuals collected), the hemichordate *Branchiostoma floridae* (14.1%), Sipuncula (9.6%), polychaetes of the genus *Prionospio* (8.1%), the ostracod *Rutiderma* sp. B (6.7%), the polychaete *Goniadides carolinae* (3.9%), and the polychaete *Armandia maculata* (3.7%). These taxa comprised 61.4% of infaunal individuals collected in October.

The numerically dominant taxa sampled during the June 2006 survey included polychaetes of the genus *Prionospio* (26% of all individuals collected), the gastropod *Caecum johnsoni* (12%), the hemichordate *Branchiostoma floridae* (3.8%), the bivalve *Semele nuculoides* (3.6%), Sipuncula (3.4%), the polychaete *Travisia hobsonae* (3.3%), the gastropod *Acteocina caniculata* (3.1%), and the amphipod *Metharpinia floridana* (3%). Together, these taxa comprised 58.2% of infaunal individuals collected in June.

Table 3-3 presents summary statistics for each of the sand borrow sites for the October 2005 and June 2006 surveys. Values are provided for number of taxa, number of individuals, species diversity, evenness, and richness.

The highest mean number of infaunal taxa per station occurred at T2 (72 taxa) and T1 (67 taxa) during the June 2006 survey. The Siesta site yielded the lowest mean number of taxa per station during both October and June (32 and 49, respectively). Highest infaunal abundances were at T2 (station average = 1,456 individuals) and T1 (station average = 826 individuals) during the June survey. Lowest mean abundances occurred in October, at T1 (station average=208 individuals) and T2 (station average = 240 individuals).

Mean values of species diversity and evenness were similar for October and June ($p>0.05$). Mean values of richness ($F=0.52$, $p<0.01$) were greater in June than October.

During October, the highest mean values of species diversity, evenness, and richness were found at Hill T2 (2.93, 0.80, and 7.32, respectively). The Siesta area had the lowest values of species diversity, evenness, and richness in October (2.21, 0.65, and 5.64, respectively).

During June, the highest mean values of species diversity and richness were at T1 (2.98 and 10.01, respectively). The highest mean values of evenness in June were at Siesta (0.75). The lowest mean values of diversity and evenness in June were at T2 (2.81 and 0.66 respectively), while the lowest richness was at Siesta (8.25).

Table 3-2. Ten most abundant taxa in grab samples from sand borrow sites Siesta, T1, and T2 for the October 2005 and June 2006 surveys off the coast of southwest Florida.

Area	October 2005 Survey		June 2006 Survey	
	Taxonomic Name	Count	Taxonomic Name	Count
Siesta	*Spio pettiboneae*	1,870	*Prionospio* spp. (LPIL)	731
	Prionospio spp. (LPIL)	744	*Lucina multilineata*	621
	Goniadides carolinae	362	Tellinidae (LPIL)	571
	Armandia maculata	352	*Goniadides carolinae*	343
	Branchiostoma floridae	252	*Branchiostoma floridae*	283
	Rutiderma sp. B	129	Nemertea (LPIL)	240
	Mysidopsis bigelowi	71	*Glycera* sp.	211
	Synelmis sp. B	67	Oligochaeta (LPIL)	205
	Rutiderma sp. A	59	*Aricidea wassi*	199
	Oligochaeta (LPIL)	54	Sipuncula (LPIL)	176
T1	*Branchiostoma floridae*	784	*Prionospio* spp. (LPIL)	6,158
	Sipuncula (LPIL)	700	*Caecum johnsoni*	1,379
	Rutiderma sp. B	470	*Branchiostoma floridae*	988
	Prionospio spp. (LPIL)	168	Sipuncula (LPIL)	971
	Oligochaeta (LPIL)	133	*Ervilia concentrica*	722
	Goniadides carolinae	120	*Travisia hobsonae*	689
	Rutiderma sp. A	103	*Metharpinia floridana*	630
	Schistomeringos sp. (LPIL)	100	*Semele nuculoides*	619
	Caecum johnsoni	89	*Acteocina caniculata*	480
	Metharpinia floridana	87	*Rutiderma* sp. B	431
T2	*Branchiostoma floridae*	828	*Prionospio* spp. (LPIL)	6,600
	Sipuncula (LPIL)	531	*Caecum johnsoni*	4,813
	Rutiderma sp. B	294	*Semele nuculoides*	1,209
	Prionospio spp. (LPIL)	165	*Acteocina caniculata*	1,109
	Acteocina caniculata	157	*Travisia hobsonae*	1,033
	Metharpinia floridana	113	*Metharpinia floridana*	889
	Streptosyllis pettiboneae	110	*Branchiostoma floridae*	704
	Parapionosyllis longicirrata	100	Sipuncula (LPIL)	608
	Rutiderma sp. A	86	*Crassinella martinicensis*	585
	Spio pettiboneae	79	Oligochaeta (LPIL)	488
All Areas	*Spio pettiboneae*	2,022	*Prionospio* spp. (LPIL)	13,489
	Branchiostoma floridae	1,864	*Caecum johnsoni*	6,208
	Sipuncula (LPIL)	1,274	*Branchiostoma floridae*	1,975
	Prionospio spp. (LPIL)	1,077	*Semele nuculoides*	1,879
	Rutiderma sp. B	893	Sipuncula (LPIL)	1,755
	Goniadides carolinae	516	*Travisia hobsonae*	1,722
	Armandia maculata	497	*Acteocina caniculata*	1,602
	Rutiderma sp. A	248	*Metharpinia floridana*	1,557
	Acteocina caniculata	239	*Crassinella martinicensis*	1,015
	Oligochaeta (LPIL)	233	*Rutiderma* sp. B	969

LPIL = Lowest Practical Identification Level

Table 3-3. Summary of infaunal statistics for the October 2005 and June 2006 surveys in sand borrow sites Siesta, T1 and T2 off the coast of southwest Florida.

Survey		October 2005			June 2006		
Area		Siesta	T1	T2	Siesta	T1	T2
Number of Stations		17	20	17	17	25	17
Number of Taxa	Mean per Station	32	34	40	49	67	72
	Standard Deviation	10.54	9.19	6.38	6.70	15.02	9.62
Number of Individuals	Mean per Station	295	208	240	383	826	1,456
	Standard Deviation	130.43	126.96	113.73	182.22	323.94	482.94
H' Diversity	Mean per Station	2.21	2.60	2.93	2.91	2.98	2.81
	Standard Deviation	0.57	0.42	0.19	0.51	0.57	0.31
J' Evenness	Mean per Station	0.65	0.75	0.80	0.75	0.71	0.66
	Standard Deviation	0.16	0.09	0.06	0.12	0.12	0.07
D Richness	Mean per Station	5.64	6.27	7.32	8.25	10.01	9.92
	Standard Deviation	1.50	1.38	0.86	1.24	2.31	1.49

Cluster Analysis

Patterns of infaunal similarity among stations were examined with cluster analysis. Cluster analysis excluded those taxa that were not identified to at least family-level, as well as taxa that comprised less than 0.1% of total abundance. When examined over both surveys, normal cluster analysis produced four groups (Groups A through D) of stations (samples) that were similar with respect to species composition and relative abundance. Four depauperate October samples from the Siesta and T1 sites were placed in an outlier Group X. Normal cluster analysis of samples is shown in Figure 3-10. Figure 3-11 shows the geographic distribution of infaunal stations grouped by normal analysis.

Station Group A was represented by four stations at the Siesta site sampled during June. These stations comprising Group A were distinguished from other stations primarily by low numbers of *Branchiostoma floridae* or common polychaete taxa from the surveys. Group A was characterized by large numbers of the bivalves *Lucina multilineata* and Tellinidae, the polychaete *Apoprionospio pygmaea*, the amphipods *Americhelidium americanum* and *Ampelisca* sp, and the ostracod *Reticulocythereis* sp. Sediments at Group A stations were relatively fine, with mean grain sizes between 0.09 and 0.15 mm. Group A sediments were between 50.8 and 60.5% calcium carbonate.

Group B was represented by thirteen stations, all at the Siesta site, and sampled during June. Stations in Group B were characterized most prominently by the polychaetes *Goniadides carolinae*, *Aricidea wassi*, *Glycera* sp. *Schistomeringos* sp. *Heteropodarke cf. heteromorpha*, *Cirrophorus cf forticirratus*, and Paraonidae. No distinguishing molluscs or crustaceans were evident in these stations. Sediments at Group B stations were sandy, with mean grain sizes between 0.25 and 0.7 mm. Group B sediments were between 63.9 and 93.7% calcium carbonate.

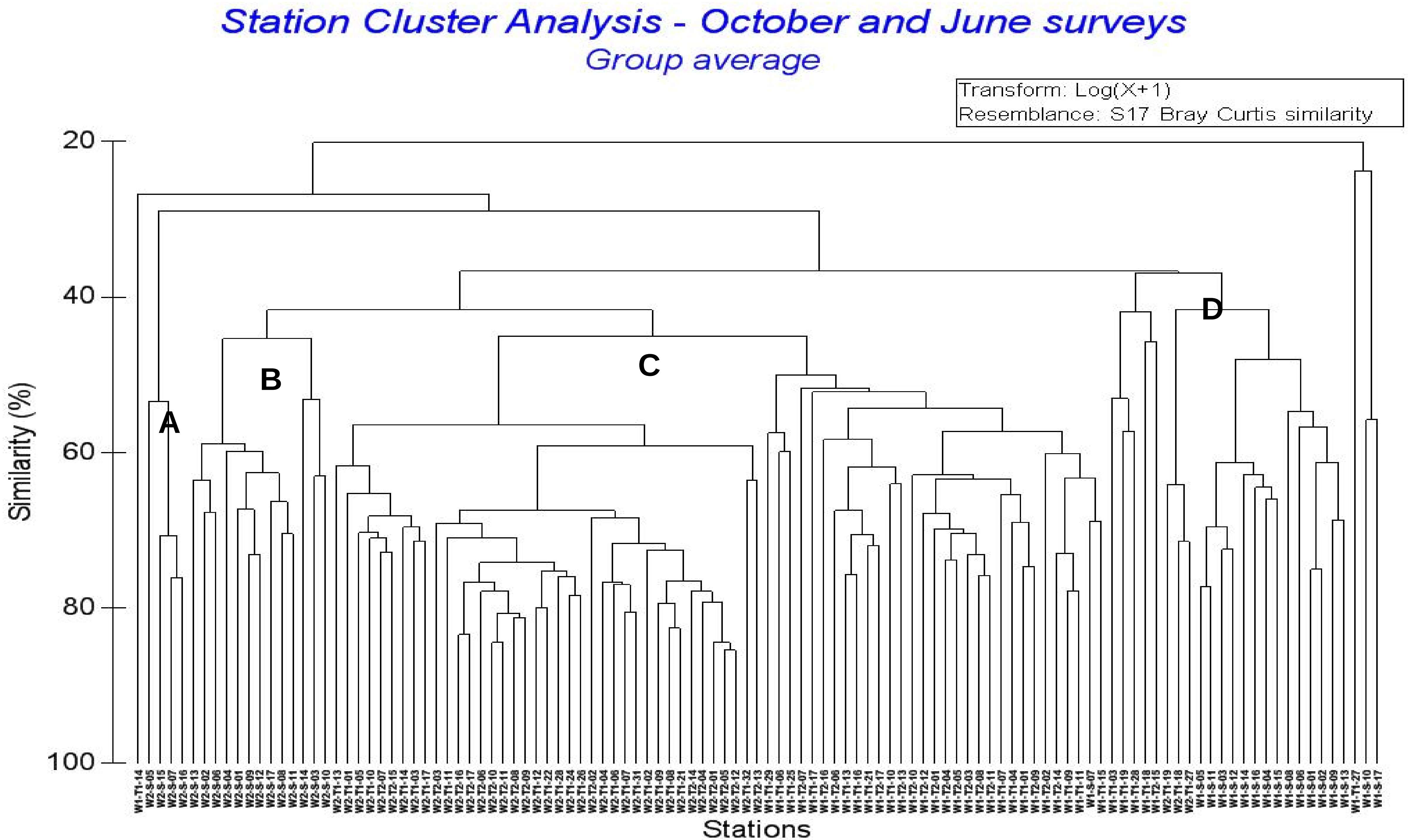


Figure 3-10. Normal cluster analysis of infaunal samples collected during the October 2005 and June 2006 surveys in sand borrow sites Siesta, T1, and T2 off southwest Florida.

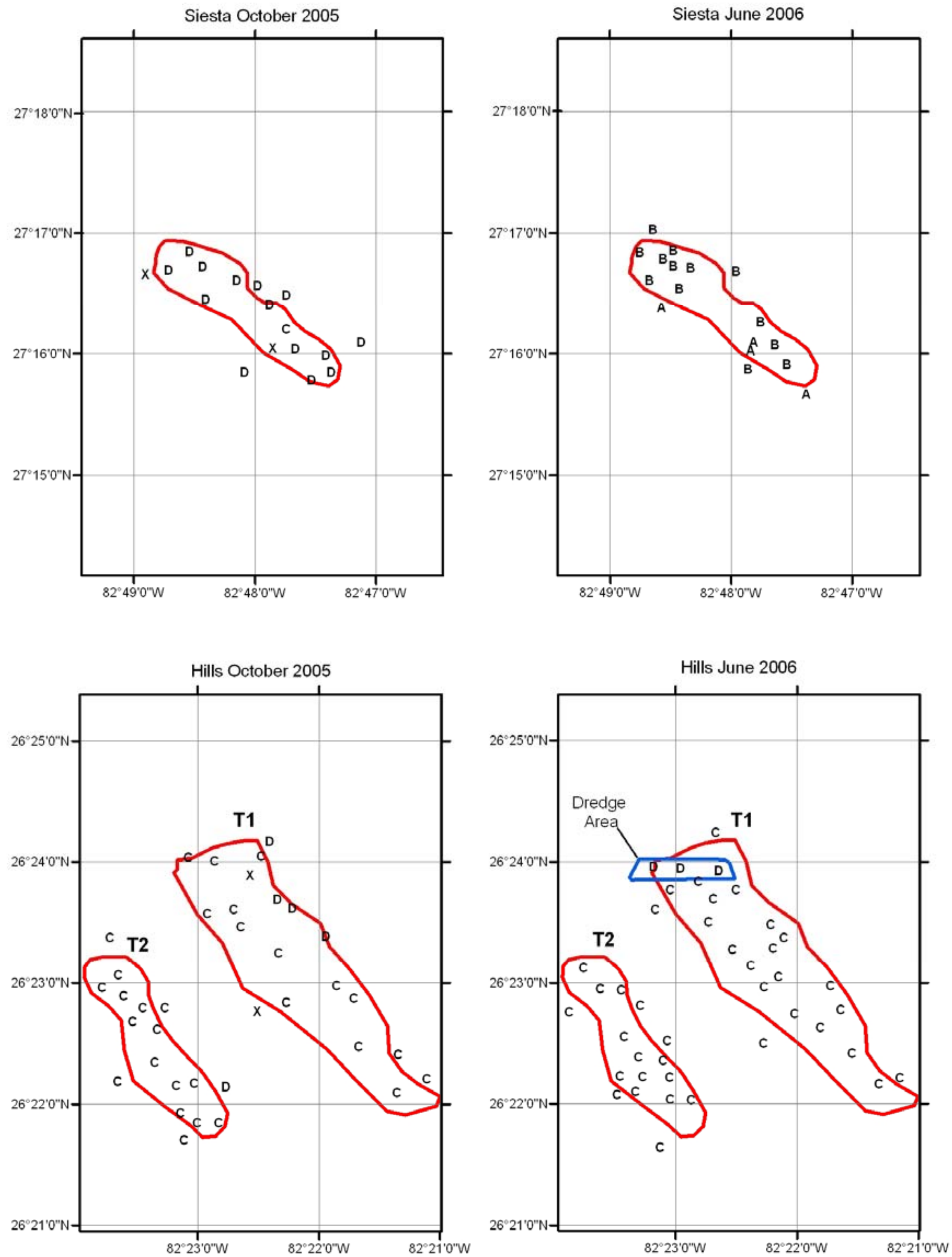


Figure 3-11. Station Groups A through D formed by normal cluster analysis of infaunal samples collected during the October 2005 and June 2006 surveys of sand borrow areas Siesta, T1, and T2 off of southwest Florida. The area dredged at Siesta during the spring of 2006 is outlined in blue. Four outlying station groups are represented by an X.

Group C (70 stations) consisted of most of the study samples, including nearly all of the T1 and T2 samples from both sample periods. Stations in Group C were characterized by the polychaetes *Prionospio* spp., *Travisia hobsonae*, the bivalves *Semele nuculoides*, *Ervilia concentrica*, and *Crassinella martinicensis*, the gastropods *Acteocina caniculata* and *Caecum johnsoni*, and the amphipod *Metharpinia floridana*. Sediments at Group C stations were sandy, with mean grain sizes between 0.26 and 0.66 mm. The percentage of calcium carbonate in Group C sediments varied widely between 12.4 and 91%.

Group D (22 stations) consisted of most of the Siesta samples and several T1 samples from the October survey, as well as all three samples taken from the area on the extreme northern end of T2 in June, following dredging operations. Stations in Group D were characterized most prominently by the polychaetes *Spio pettiboneae* and *Armandia maculata*, and the crustacean *Mysidopsis bigelowi.* Sediments at Group D stations were sandy, with mean grain sizes between 0.27 and 0.64 mm. The percentage of calcium carbonate in Group D sediments varied widely between 20.4 and 90.9%. Overall, stations in Group D were relatively depauperate, having few taxa and low abundances. The taxonomic composition of station D groups was dominated by polychaetes, with a few crustacean taxa present, while molluscs were almost entirely absent.

The inverse cluster analysis examining both the October and June surveys resulted in four groups of taxa (Groups 1 through 4) that reflected their co-occurrence in the samples (Figure 3-12; Table 3-4). Many infauna included in the cluster analysis were relatively rare and heterogeneously distributed; these taxa were not included in the four groups defined by the inverse analysis.

Taxa in Group 1 were not particularly abundant (not in the top 10 most abundant taxa of either survey), but were found in all three study areas during both surveys. These taxa occurred primarily in Station Groups B and C. Sediments at these station groups were sandy, with varying percentages of calcium carbonate. Group 1 taxa included the polychaetes *Parapionosyllis longicirrata*, *Streptosyllis pettiboneae*, and *Glycera* sp., the amphipod *Acanthohaustorius pansus*, and the bivalve *Diplodonta* sp.

Group 2 taxa included some of the more abundant and homogeneously distributed taxa collected during the study. These taxa were collected in all three study areas during both surveys. Group 2 taxa were strongly associated with Station Group C, composed of sandy sediments with varying percentages of calcium carbonate. These taxa included the gastropods *Caecum johnsoni* and *Acteocina caniculata*, the bivalves *Crassinella martinicensis* and *Semele nuculoides*, the amphipod *Metharpinia floridana*, and the polychaete *Travisia hobsonae*.

Taxa in Group 3 also included taxa, which were widespread across all three study sites and both surveys. However, Group 3 taxa were not associated with any particular station group. Group 3 taxa included the polychaetes *Prionospio* spp. and *Armandia maculata*, the lancelet *Branchiostoma floridae*, and the ostracods *Rutiderma* sp A and sp. B. Numerically, these five taxa accounted for 34% of individuals collected during the study.

Group 4 taxa were associated primarily with Station Group A, composed of fine sediments, with 50 to 60% calcium carbonate. Members of Group 4 were crustaceans and molluscs, including the amphipods *Americhelidium americanum* and *Metatiron triocellatus*, cumaceans of the family Bodotriidae, and the bivalves *Lucina multilineata* and Tellinidae.

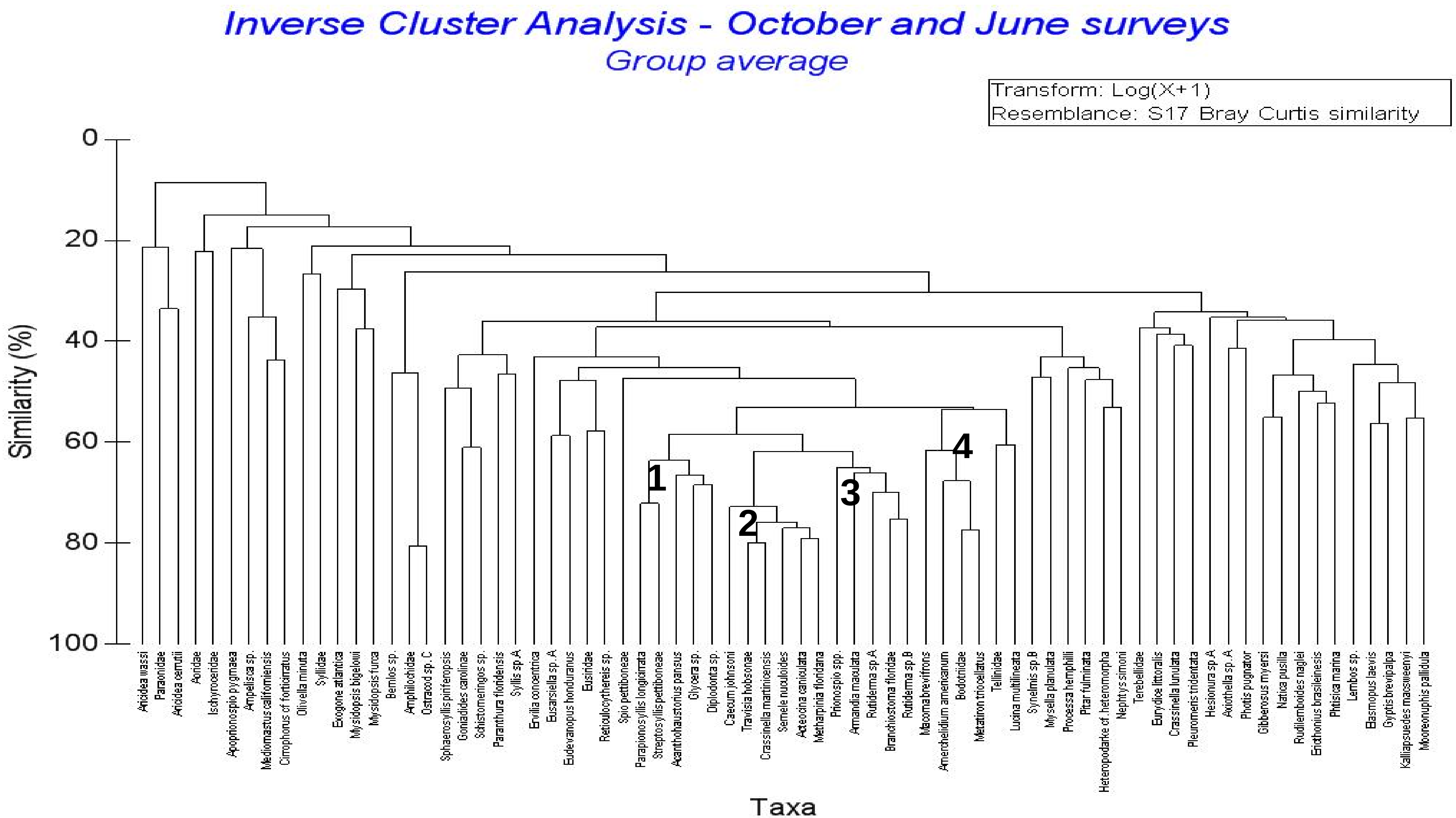


Figure 3-12. Inverse cluster analysis of infaunal samples collected during the October 2005 and June 2006 surveys in sand borrow sites Siesta, T1, and T2 off southwest Florida.

Table 3-4. Infaunal taxa groups resolved from inverse cluster analysis of all samples collected in the October 2005 and June 2006 surveys in sand borrow sites Siesta, T1, and T2 off the coast of southwest Florida.

Taxa Group	Taxa	Category
1	*Parapionosyllis longicirrata*	polychaete
	Streptosyllis pettiboneae	polychaete
	Glycera sp. (LPIL)	polychaete
	Acanthohaustorius pansus	amphipod
	Diplodonta sp. (LPIL)	bivalve
2	*Travisia hobsonae*	polychaete
	Metharpinia floridana	amphipod
	Caecum johnsoni	gastropod
	Acteocina caniculata	gastropod
	Crassinella martinicensis	bivalve
	Semele nuculoides	bivalve
3	*Armandia maculata*	polychaete
	Prionospio spp (LPIL)	polychaete
	Branchiostoma floridae	chordate
	Rutiderma sp A	ostracod
	Rutiderma sp B	ostracod
4	*Americhelidium americanum*	amphipod
	Metatiron triocellatus	amphipod
	Bodotriidae (LPIL)	cumacean
	Lucina multilineata	bivalve
	Tellinidae (LPIL)	bivalve

Data collected during the two surveys were analyzed using cluster analysis to determine which environmental factors most affected the distribution of station groups identified by normal cluster analysis as being similar with respect to species composition and relative abundance. The non-metric multi-dimensional scaling plot of station sediment parameters appears in Figure 3-13. This plot shows a strong relation between sediment parameters (mean grain size, percent fines, and percent carbonate) and station groups formed by normal cluster analysis. Stations in Group C are grouped together, as is Station group A. Station Groups B and D are somewhat overlapping. Station Groups B and D primarily occurred in the Siesta study area (see Figure 3-11), but were completely separated temporally. At the Siesta site, station group B occurred only in June, and Station group D occurred only in October.

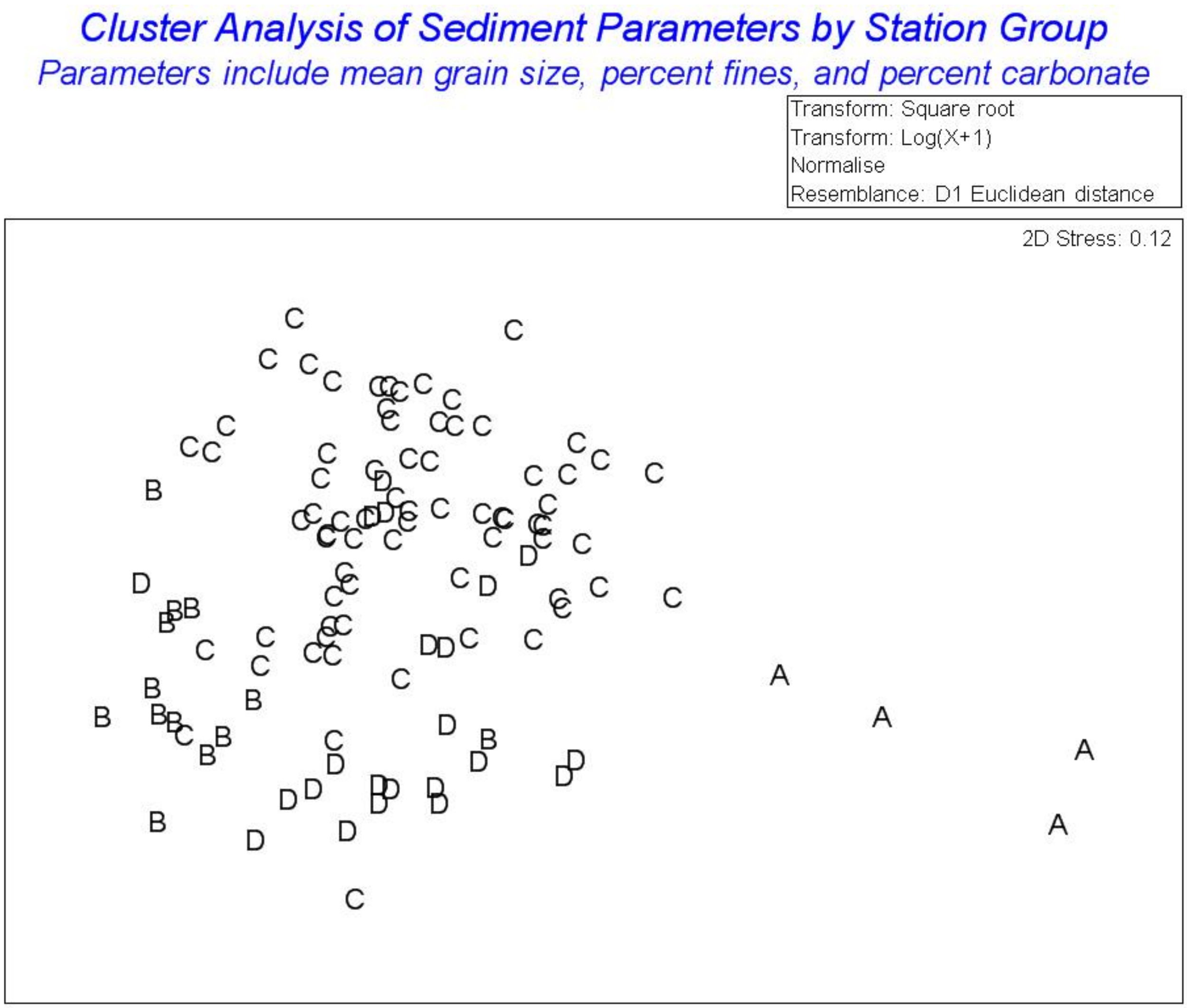


Figure 3-13. Multi-dimensional scaling plot of station sediment parameters and station groups identified by normal cluster analysis as being similar with respect to species composition and relative abundance.

Epifauna Camera Sled Results

Due to a recent storm passage prior to the first survey conducted in October 2005 and possibly the HAB event, marine flora and fauna, as well as surface features, that could be identified from the video survey were limited due to low visibility and were generally comprised of large organisms. Terms abundant, common, and numerous are used interchangeably to describe the video survey results and to qualify the relative presence of organisms. Abundant, common, and numerous simply mean that a taxon was frequently observed in transects of a particular study site, as opposed to a taxon seen only once or infrequently, which was described as present. Exact numbers cannot be determined, as images may be blurry or the animal is moving too fast, or it is at the edge of the screen frame.

Four video transects were conducted at each of the three study areas and a single transect was performed between T1 and T2. All transects were performed during daylight hours, when natural lighting provides a wider field of view. However, this method may under represent fish use of the shoals if fish move onto the shoals during the night. Few fish were seen during the video transects, though many were caught in otter trawls, some of which occurred at night. Still images from the video transects appear below in Figures 3-14 through 3-17

At the Siesta study area, sand waves were common, though some areas were flat, and rock was observed in several spots on transect S-3, which was located about a quarter mile northeast of the shoal. Sand waves were aligned southeast to northwest, paralleling the direction of the Siesta shoal. Several species of algae were present in some areas where sand waves were lacking. Several large burrows were present, and may be snapping shrimp burrows. The sand dollar *Encope michelini* was the dominant macroinvertebrate observed, and the margined sea star *Astropecten articulatus* was present, though neither species was abundant. The sand dollar *Leodia sexiesperforata* and the drill *Terebra dislocata* were also identified in the video. No fish or crustaceans were observed in the Siesta area video transects.

At the T1 area, sand waves were the dominant bedform, though in some areas they were poorly defined, and rocky bottom with algae was observed in several spots on transect T1-5, which was located about a quarter mile northeast of the shoal. Sand waves were aligned southeast to northwest, paralleling the direction of the T1 shoal. Several large burrows were observed. The sand dollar *Encope michelini* was the dominant macroinvertebrate observed. The sand dollar *Leodia sexiesperforata* was also present, but not abundant. Several unidentified fish appear in the video, but no crustaceans were observed in the T1 transects.

At the T2 area, the seabed was composed of well-formed sand waves. Sand waves were aligned southeast to northwest, paralleling the direction of the T2 shoal. Several large burrows, possibly crustacean, were observed. Small polychaete sediment mounds were present. The sand dollar *Encope michelini* was the dominant macroinvertebrate observed, and was common. The sea star *Luidia clathrata* was also present, but not abundant. No fish, crustaceans, or algae were observed in the T2 transects.

The area between T1 and T2 was markedly different from the shoals themselves. This area was predominately hardbottom, with cavities eroded into the rock. Several sand channels were observed between rock ledges. Fish, algae, finger corals, sponges, and the sea pansy *Renilla reniformis* were observed. The sand dollar *Encope michelini* and an unidentified sand dollar were present in areas of sand.

Figure 3-14. Sand dollar covered bottom on T1, October 2005.

Figure 3-15. Arrowhead sand dollars *Encope michelini*, on T2, October 2005.

Figure 3-16. The sea star Astropecten articularis on the Siesta Shoal, October 2005.

Figure 3-17. Infaunal fecal mounds on T2, October 2005.

3.3.4 Fisheries Results: Fishes, Ichthyoplankton, and Fisherman Survey

Trawl Collections

Sixteen successful otter trawl tows were made during the fall 2005 survey and 13 tows were made during the spring 2006. The mean area trawled (±1 SD) was 0.45 ± 0.09 ha and was similar across surveys. Combined, 2,317 fishes from 50 identifiable taxa were collected (Table 3-5). Catches were numerically dominated by small-bodied benthic species; the Gulf of Mexico barred searobin (*Prionotus martis*) and leopard searobin (*P. scitulus*) alone composing 67% of the catch. Other common species taken included the sand seabass (*Diplectrum formosum*), juvenile grunts (family Haemulidae), and twospot flounder (*Bothus robinsi*), all of which are bottom associates. The most speciose families were the Ophidiidae (cusk eels, 6 species), Serranidae (groupers and sea basses, 5 species), Triglidae (sea robins, 4 species), and Paralichthyidae (largetooth flounders, 4 species). Pelagic fishes were considerably less abundant but included Atlantic bumper (*Chloroscombrus chrysurus*) and Atlantic thread herring (*Opisthonema oglinum*). With the exception of juvenile grunts, fishes with a strong affinity for hardbottom reef substrates were uncommon. Grunts were also the only abundant taxa collected which are of any direct economic value to southwest Florida. T1 (combined inside and outside sites) produced highest mean fish densities (272 fish per ha) when averaged across surveys, largely due to high sea robin catches, and also produced the most taxa (40). T2 yielded the fewest taxa (11) and Siesta Shoals the lowest fish density (73 fish per ha). The number of total species collected and overall fish density was similar inside vs. outside potential sand borrow areas but was considerably elevated during the spring 2006 survey. Further, much greater numbers of fish species were collected during the spring 2006 survey (42) versus the fall 2005 survey (23) in spite of the slightly lower number of tows.

Macroinvertebrate trawl catches were dominated by the iridescent swimming crab (*Portunus gibbesii*), five-notched sand dollar (*Encope michelini*), penaeid shrimp (both *Litopenaeus setiferus* and *Farfantepenaeus duorarum*), and blotched swimming crab (*Portunus spinimanus)*. Decapod crustaceans comprised 68% of the 1,252 individuals recovered (total both surveys). On average, 97 macroinvertebrates were collected per ha but density varied widely between sites ranging from 43 per ha at Siesta Shoals to 169 per ha at T1.

Results of non-metric multidimensional scaling suggest that the fish and macroinvertebrate fauna was similar across sand borrow sites (T1, T2, Siesta Shoals) and inside versus outside individual sites (Figure 3-18). However, greater discrimination in community composition was apparent between the October 2005 and June 2006 surveys. This was largely the result of highly variable sea robin densities with the leopard searobin (*Prionotus scitulus*) dominating catches from fall 2005 and the Gulf of Mexico barred searobin (*P. martis*) from spring 2006.

Table 3-5. Fishes collected with otter trawls within and adjacent to three proposed borrow sites along the southwest Florida continental shelf.
Asterisk denotes species managed under a fishery management plan in the Gulf of Mexico.

Scientific Name	Common Name	Otter Trawl Catch Per Unit Effort (Individuals Per Hectare)											Fish Size (Standard Length)					
		Total Captured	All Sites	Inside 2005	Outside 2005	Inside 2006	Outside 2006	Inside Total	Outside Total	Siesta Shoals Total	T1 Total	T2 Total	Mean Inside	SE Inside	Measured Inside	Mean Outside	SE Outside	Measured Outside
Prionotus martis	Gulf of Mexico barred searobin	1278	98.6	0.0	0.0	209.1	205.1	108.4	81.5	10.8	144.7	114.0	104.7	0.6	218	107.9	1.2	95
Prionotus scitulus	Leopard searobin	284	21.9	59.7	15.1	0.0	2.1	28.8	9.9	12.2	40.2	6.7	61.4	2.2	162	69.5	6.5	28
*Diplectrum formosum**	Sand seabass	193	14.9	1.8	4.2	31.6	20.8	17.2	10.8	9.7	19.6	13.2	117.6	1.9	137	111.4	4.7	50
Haemulon spp.	Grunt	171	13.3	0.0	0.7	18.3	49.0	9.5	19.9	0.9	31.9	0.0	44.9	2.8	57	37.4	1.2	33
Bothus robinsi	Twospot flounder	61	4.7	9.3	7.4	0.7	0.0	4.9	4.4	0.6	4.2	8.9	81.3	2.7	40	86.0	3.4	21
Synodus foetens	Inshore lizardfish	55	4.2	2.0	2.8	8.2	2.1	5.2	2.5	4.8	3.0	5.3	159.0	8.7	43	163.2	19.4	12
Eucinostomus gula	Silver jenny	40	3.1	0.0	0.7	8.9	0.0	4.6	0.4	10.8	0.4	0.0	107.5	1.1	36	129.5	0.5	2
Stephanolepis hispidus	Planehead filefish	21	1.6	0.0	0.0	3.7	2.7	1.9	1.1	2.8	2.1	0.0	66.3	3.5	16	71.4	15.2	5
Chloroscombrus chrysurus	Atlantic bumper	19	1.5	0.0	0.0	4.4	0.0	2.3	0.0	5.4	0.0	0.0	121.5	2.3	19			
Opisthonema oglinum	Atlantic thread herring	18	1.4	4.5	0.0	0.0	0.0	2.2	0.0	0.0	3.4	0.0	62.5	3.1	17			
Acanthostracion quadricornis	Scrawled cowfish	14	1.1	0.5	1.4	1.9	0.0	1.2	0.8	2.6	0.8	0.2	169.1	5.4	10	141.3	4.7	4
Lagodon rhomboides	Pinfish	14	1.1	0.0	0.4	2.3	1.6	1.2	0.8	2.8	0.8	0.0	114.6	2.4	10	143.5	8.5	4
Citharichthys macrops	Spotted whiff	13	1.0	1.5	0.4	1.4	0.0	1.5	0.2	2.6	0.4	0.5	108.1	6.6	12	116.0	0.0	1
Lepophidium brevibarbe	Shortbeard cusk-eel	11	0.8	0.0	0.0	0.0	5.9	0.0	2.3	0.0	2.1	0.0						
Archosargus probatocephalus	Sheepshead	8	0.6	0.0	0.0	0.0	4.3	0.0	1.7	0.0	1.5	0.0				40.1	1.1	8
Ophidion beani	Cusk-eel	8	0.6	1.0	0.4	0.7	0.0	0.8	0.2	0.0	1.5	0.0	166.3	20.0	6	160.0	0.0	1
Pareques acuminatus	High-hat	8	0.6	0.0	0.0	0.0	4.3	0.0	1.7	0.0	1.5	0.0				43.1	4.3	8
Haemulon aurolineatum	Tomtate	7	0.5	0.0	2.5	0.0	0.0	0.0	1.5	0.0	1.3	0.0				161.6	8.9	7
Haemulon plumierii	White grunt	7	0.5	0.0	1.1	0.0	2.1	0.0	1.5	0.0	1.3	0.0				93.9	31.2	7
Phaeoptyx pigmentaria	Dusky cardinalfish	7	0.5	0.0	0.0	0.0	3.7	0.0	1.5	0.0	1.3	0.0				32.3	1.4	7
Ophidion grayi	Blotched cusk-eel	6	0.5	0.3	0.0	0.7	1.1	0.5	0.4	0.0	1.1	0.0	202.0	18.2	4			
Prionotus rubio	Blackwing searobin	5	0.4	0.0	0.4	0.9	0.0	0.5	0.2	1.1	0.0	0.2	117.0	15.0	4	60.0	0.0	1
Scorpaena grandicornis	Plumed scorpionfish	5	0.4	0.0	0.0	0.5	1.6	0.2	0.6	0.3	0.8	0.0	91.0	4.0	2	55.7	29.7	3
Ophidion holbrookii	Band cusk-eel	4	0.3	0.0	0.0	0.9	0.0	0.5	0.0	0.0	0.8	0.0	134.0	22.6	4			
Ophidion selenops	Mooneye cusk-eel	4	0.3	0.0	0.0	0.9	0.0	0.5	0.0	0.0	0.8	0.0	89.5	3.6	4			
Prionotus tribulus	Bighead searobin	4	0.3	0.0	0.4	0.7	0.0	0.4	0.2	0.3	0.6	0.0	116.7	4.7	3	166.0	0.0	1
Sardinella aurita	Spanish sardine	4	0.3	0.5	0.0	0.5	0.0	0.5	0.0	0.6	0.4	0.0	75.5	5.3	4			
Serranus subligarius	Belted sandfish	4	0.3	0.0	0.4	0.0	1.6	0.0	0.8	0.0	0.8	0.0				44.0	2.0	4
Syacium gunteri	Shoal flounder	4	0.3	0.0	0.0	0.7	0.5	0.4	0.2	0.9	0.2	0.0	105.0	6.8	3			
Ancylopsetta ommata	Gulf of Mexico ocellated flounder	3	0.2	0.0	0.0	0.5	0.5	0.2	0.2	0.0	0.4	0.2	127.0	0.0	1	142.0	0.0	1
Hippocampus erectus	Lined seahorse	3	0.2	0.0	0.0	0.0	1.6	0.0	0.6	0.0	0.6	0.0				176.7	12.9	3
Menticirrhus saxatilis	Northern kingfish	3	0.2	0.0	0.0	0.7	0.0	0.4	0.0	0.9	0.0	0.0	164.3	5.5	3			
Pareques umbrosus	Cubbyu	3	0.2	0.0	0.0	0.0	1.6	0.0	0.6	0.0	0.6	0.0				103.3	5.7	3
Rypticus maculatus	Whitespotted soapfish	3	0.2	0.0	0.0	0.0	1.6	0.0	0.6	0.0	0.6	0.0				109.3	7.6	3
Chilomycterus schoepfii	Striped burrfish	2	0.2	0.3	0.0	0.2	0.0	0.2	0.0	0.3	0.2	0.0	175.0	15.0	2			
Citharichthys spp.	Whiff	2	0.2	0.0	0.0	0.5	0.0	0.2	0.0	0.6	0.0	0.0	79.0	7.0	2			
*Epinephelus morio**	Red grouper	2	0.2	0.0	0.0	0.0	1.1	0.0	0.4	0.0	0.4	0.0				53.5	3.5	2
Etropus microstomus	Smallmouth flounder	2	0.2	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.2	121.5	1.5	2			
Syngnathus louisianae	Chain pipefish	2	0.2	0.0	0.0	0.5	0.0	0.2	0.0	0.6	0.0	0.0	306.0	0.0	1			
Acanthostracion polygonius	Honeycomb cowfish	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				180.0	0.0	1

Table 3-5. Fishes collected with otter trawls within and adjacent to three proposed borrow sites along the southwest Florida continental shelf. Asterisk denotes species managed under a fishery management plan in the Gulf of Mexico. (*continued*)

Aluterus schoepfii	Orange filefish	1	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	320.0	0.0	1			
Calamus proridens	Littlehead porgy	1	0.1	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.2	0.0				77.0	0.0	1
Diodon spp.	Porcupinefish	1	0.1	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.2	0.0				155.0	0.0	1
*Diplectrum bivittatum**	Dwarf sand perch	1	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.2	0.0	71.7	0.0	1			
Eucinostomus harengulus	Tidewater mojarra	1	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.0	85.0	0.0	1			
Jenkinsia majua	Little-eye round herring	1	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.0	68.0	0.0	1			
*Lutjanus griseus**	Gray snapper	1	0.1	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.2	0.0				170.0	0.0	1
*Lutjanus synagris**	Lane snapper	1	0.1	0.0	0.0	0.0	0.5	0.0	0.2	0.0	0.2	0.0				138.0	0.0	1
Nicholsina usta	Emerald parrotfish	1	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.2	75.0	0.0	1			
Ophidion spp.	Cusk-eel	1	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	60.0	0.0	1			
Ophidion welshi	Crested cusk-eel	1	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.2	0.0	168.0	0.0	1			
Prionotus spp.	Searobin	1	0.1	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.2	0.0				38.0	0.0	1
Sphoeroides nephelus	Southern puffer	1	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.0	127.0	0.0	1			
Upeneus parvus	Dwarf goatfish	1	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.0	60.0	0.0	1			
	Total Fishes	2317	2317	327	112	1127	751	1454	863	256	1438	623						
	No. Trawls		29	9	7	8	5	17	12	7	13	9						
	Mean Fish Per Hectare		178.7	82.4	39.4	301.2	315.3	195.7	149.0	72.9	271.6	149.8						
	Unique Taxa		50	13	18	31	21	35	33	25	40	11						

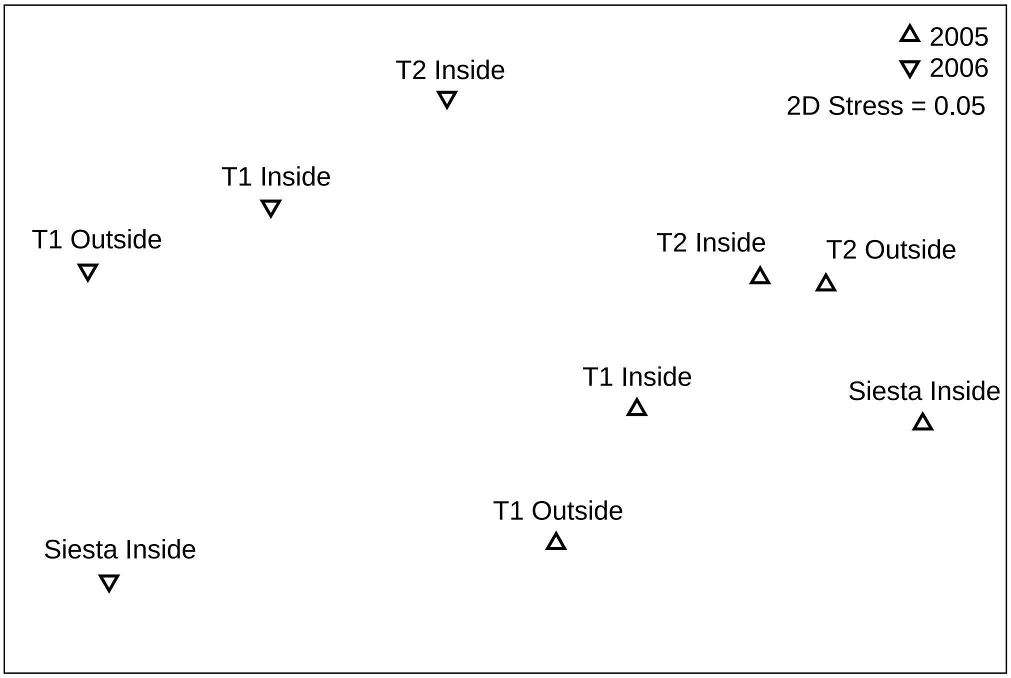


Figure 3-18. Spatiotemporal differences in fish and macroinvertebrate community structure from otter trawls inside and outside sand borrow sites of the southwest Florida continental shelf as demonstrated by non-metric multi-dimensional scaling. Interpoint distances are proportional to overall faunal similarity. Sites where hardbottom substrates precluded sample collection are excluded.

Feeding Habits

The diet of 342 fishes examined from seven demersal taxa contained prey (Table 3-6). Most fishes examined typically had small amounts of well-digested prey in their stomachs with a mean fullness index and mean digestion index of 1.4. Nonetheless, 13 general prey categories were recognized with shrimp and lancelets (*Branchiostoma* spp.) as the most important prey items. Crustaceans were the most diverse prey group identified although many (e.g., mysids, copepods, isopods, amphipods) appeared of relatively minor importance. Fish prey were only an important dietary constituent for the inshore lizardfish (*Synodus foetens*), a species known for its piscivorous habits.

Ichthyoplankton Collections

Plankton sampling yielded 621 fish larvae in 30 total tows (Table 3-7). Larval densities were highest during the fall 2005 survey 1 with gobies and the striped anchovy (*Anchoa hepsetus*) most abundant, all collected in sub-surface samples. Larval abundance was extremely low at all sites during the spring 2006 survey; only 104 individuals from 14 families and 17 identifiable taxa were taken in 18 collections. One taxa, *Lutjanus* spp. (snapper) is considered a reef associate of potential economic value. Most other fishes identified were larvae of pelagic forage species or small-bodied demersal taxa.

Table 3-6. Summary of prey items for seven species of demersal fish species common to proposed borrow sites off southwest Florida.

Scientific Name (Common Name)				Prey Category Index of Relative Importance (IRI)												
	No. Fish Analyzed	Mean Fullness Index	Mean Digestion Index	Polychaete	Cumacean	Mysid	Copepod	Amphipod	Isopod	Stomatopod (larvae)	Shrimp	Crab	Unident. Crustacean	*Branchiostoma* spp.	Cephalopod	Fish
Prionotus scitulus (Leopard searobin)	88	1.5	1.2	0.2	0.0	0.9	0.4	0.0	0.1	0.0	56.9	0.0	1.3	5.4	0.0	0.0
Prionotus martis (Gulf of Mexico barred searobin)	77	0.9	1.2	0.2	0.1	0.4		5.9			0.4	0.0		26.4		
Diplectrum formosum (Sand seabass)	58	1.6	1.2	0.4	0.0	0.0	0.0	2.9	0.0	1.0	25.5	8.2	8.1	2.6	0.0	0.1
Bothus robinsi (Twospot flounder)	55	1.6	1.0		0.0		0.0	0.0		0.0	28.6	0.1	0.3	25.8	0.0	
Synodus foetens (Inshore lizardfish)	55	0.8	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	0.0	0.0	0.0	0.3	33.6
Citharichtyes macrops (Spotted whiff)	7	1.7	1.5			24.3					98.4					
Etropus microstomus (Smallmouth flounder)	2	1.5	2.5	50.0										50.0		

Table 3-7. Larval fish densities collected in neuston (surface) and plankton (sub-surface) samples within sites.
Densities are averaged across sites for each year and are standardized to no. fish per 1000 m^3 water filtered. Larval fish sizes (standard length [SL] or notocord length [NL]) are available for 2006 only.

Scientific Name	Common Name	Larval Fish CPUE (No. per 1000 m^3 water filtered)					Larval Size (SL or NL)		
		Total Captured	Neuston 2005	Plankton 2005	Neuston 2006	Plankton 2006	Mean SL	SE	Measured
Gobiidae	Goby	294		755.2	0.4	0.3	7.3	2.3	4
Anchoa hepsetus	Striped anchovy	177		460.9					
Opisthonema oglinum	Atlantic thread herring	38			0.2	5.9	11.5	0.3	38
Clupeidae	Herring	29			1.6	3.4	7.9	0.5	29
Paralichthyidae	Large-tooth flounder	16		41.7					
Achiridae	American sole	14		36.5					
Citharichthys spp.	Flounder	11			0.2	1.6	5.1	0.4	11
Menticirrhus spp.	Whiting	8		20.8					
Synodus foetens	Inshore lizardfish	4			0.6	0.2	11.8	0.9	4
Hyporhamphus spp.	Halfbeak	3	5.8	2.6	4.3	6.1			
Sardinella aurita	Spanish sardine	2			0.2	0.2	13.5	0.5	2
Sparidae	Porgy	2				0.3	3.6	0.0	2
Monacanthus ciliatus	Fringed filefish	2			0.2	0.2	12.6	1.4	2
Ostraciidae	Boxfish	2			0.2	0.2	5.7	2.2	2
Prionotus spp.	Searobin	2		5.2	4.3	14.3			
Phycidae	Phycid hake	1			0.2		6.6		1
Syngnathus louisianae	Chain pipefish	1				0.2	12.0		1
Decapterus spp.	Scad	1			0.2		5.5		1
Lutjanus spp.	Snapper	1				0.2	4.7		1
Gerreidae	Mojarra	1				0.2	5.1		1
Sciaenidae	Drum	1		2.6					
Larimus fasciatus	Banded drum	1				0.2	3.2		1
Diodontidae	Porcupinefish	1				0.2	5.8		1
Unidentified	Unidentified	9		15.6		0.5			
	Total Captured	621	2	515	20	84			
	Mean No. Per 1000m^3		5.8	1341.1	12.6	33.8			
	No. Tows		6	6	9	9			
	Mean Volume Sampled		343 m^3	384 m^3	576 m^3	691 m^3			
	Unique Taxa		1	7	11	15			

Results of Fishermen Surveys

In May and June 2006, (23) fishermen were interviewed in Tampa Bay and in Sarasota and Lee Counties. Respondents included boat captains, charter fishing guides, and owners of marine supply and service stores. In questions, 1-5 survey participants were asked about fishing practices on and/or near the study sites. Their responses are summarized in Table 3-8. For questions 6-6b, participants were asked for additional concerns or comments about dredging in the study areas see Appendix B8 for a discussion of the survey and all responses provided in see Bi-Monthly Progress Report June 2007 in Appendix B.

Respondents often provided more than one response per question. For example, two respondents were commercial diving guides and recreational anglers, all others were divided nearly evenly between commercial (43%) and recreational (48%). Grouper, red snapper, shrimp other pelagic fish, reef fish, hog fish, and lobster were the targeted catch. Fishing habitats preferred by percentage of participants were 74% hard bottom, 57% sand bottom, 48% artificial reef, and 26% open water. Thirty percent of participants reported on site use of T1 and T2 Shoals for fishing as opposed to 4% for Siesta Shoal. Survey responses for fishing 5 miles off T1 and T2 Shoals were 43% as opposed to 9% for fishing 5 miles off Siesta Shoal. The reported types of gear used included trawl nets, and rod and reel. Eleven of twelve respondents preferred fishing year round as opposed to a particular season.

For questions 6, 6a, and 6b fishermen were asked three related questions on their perceptions of the impacts that dredging may cause to fishing. Forty-seven percent (11) said there was no direct impact and twenty-two percent said indirect impacts from dredging did not affect them or did not apply to them. Comments ranged from dredging has a positive effect on fishing to the perception that certain fishing problems may be indirectly related to dredging see Bi-Monthly Progress Report April 2007 in Appendix B for all comments.

3.3.5 Marine Mammals, Sea Turtles and Sea Birds

Results of the marine mammals, sea turtles, and sea birds surveys during the October 2005 and June 2006 field events differed in the total number of species observed and the diversity of species encountered. Between the two field events, nearly 55 hours of visual observation for marine fauna and avian species, and approximately 5 hours of passive acoustic monitoring for marine mammals were conducted. Table 3-9 contains species observed, the number of individuals, and relevant field notes from the 2005 and 2006 survey events.

Results of October 2005 Field Event

Visual observations were documented in 2005 of the federally protected species loggerhead sea turtle (*Caretta caretta*). The two sightings of loggerhead sea turtles occurred on the 6th of October 2005. The first was a dead turtle spotted by the Captain of the R/V Suncoaster while traveling from the T1/T2 area to the Siesta Shoal and the second was spotted during regular visual watches. Two bottlenose dolphins (*Tursiops truncatus*) were visually observed. The first sighting was in rough sea conditions. The second was a brief look at the dorsal of an individual and it was not spotted again. The two most common sea birds spotted were the magnificent frigatebirds (*Fregata magnificens*) and the royal tern (*Sterna maxima*). Other birds less frequently seen were Eurasian collared-dove (*Streptopelia decaocto*), osprey (*Pandion haliaetus*), and laughing gulls (*Larus atricilla*). The Record of Sighting containing all marine mammals and sea turtle sightings appears in Appendix B.

Table 3-8. 2006 MMS Florida West Coast Fisherman Survey Results (Questions 1-5).

Question	1 Fishing or Diving?					2 Target species?	3 Habitat Targets?				4 On Site?								5 Within 5 Miles of site?							
Sample	**Fishing**	**Diving**	**Commercial**	**Guide**	**Recreation**	**Target species**	**HB**	**SB**	**Artificial Reef**	**Open H20**	**No**	**Yes**	**T1**	**T2**	**Siesta Shoal**	**Target**	**Gear**	**Season**	**No**	**Yes**	**T1**	**T2**	**Siesta Shoal**	**Target**	**Gear**	**Season**
West-MMS-1		1		1	1	All	1	1	1		1								1							
West-MMS-2	1			1		Grouper, Snapper	1				1						Rod & Reel			1	1	1	1	Grouper, Snapper	Rod & Reel	All
West-MMS-3	1			1	1	Grouper, Snapper	1					1	1	1			Rod & Reel			1	1	1		Grouper, Snapper	Rod & Reel	
West-MMS-4	1				1	Grouper, Snapper, & Reef fish	1		1		1						Rod & Reel		1							
West-MMS-5	1		1			Shrimp	1	1				1				Shrimp	Trawl Nets	All		1				Shrimp	Trawl Net	
West-MMS-6	1		1			Shrimp	1	1				1	1	1		Shrimp	Nets	All		1	1	1		Shrimp	Net	All
West-MMS-7	1		1			Snapper, Grouper	1				0		1	1					0		1	1				
West-MMS-8	1		1			Shrimp	1	1				1	1	1		Shrimp	Net	All		1	1	1		Shrimp	Net	
West-MMS-9		1		1	1	Shark teeth		1			1								1							
West-MMS-10	1		1			Shrimp	1	1			1								1							
West-MMS-11	1			1	1	Bottom / Pelagic	1	1	1	1	1								1							
West-MMS-12	1		1			Shrimp		1				1	1	1		Shrimp	Nets	All		1	1	1		Shrimp	Net	
West-MMS-13	1		1			Shrimp		1			1								1					Shrimp	Trawls	All
West-MMS-14	1				1	Bottom fish, Grouper, Snapper, Grunt	1	1	1			1	1	1		Grouper, Snapper & Grunt		All		1	1	1		Grouper, Snapper, & Grunt		All
West-MMS-15	1				1	Grouper, Snapper	1		1		1								1							
West-MMS-16	1				1			1	1	1	1								1							
West-MMS-17	1				1	Hog lobster			1	1	1								1							
West-MMS-18	1				1	All	1	1	1	1	0		1	1	1			All	0		1	1	1			
West-MMS-19	1				1	Snapper, Grouper	1		1		1								1							
West-MMS-20	1		1			Shrimp		1			1										1	1		Shrimp	Trawls	All
West-MMS-21	1		1			Snapper, Grouper, Dolphin, other pelagic	1		1	1	1								1							
West-MMS-22	1		1			Snapper, Grouper,	1		1	1	1								1							
West-MMS-23	1			1		Grouper, Snapper, other	1				1									1	1	1		Grouper, Mangrove Snapper	Rod & Reel	Spring & Winter
Totals	21	2	10	6	11		17	13	11	6	15	6	7	7	1				12	8	10	10	2			
% of Totals	91%	9%	43%	26%	48%		74%	57%	48%	26%	65%	26%	30%	30%	4%				52%	35%	43%	43%	9%			

Table 3-9. Marine Mammals, Sea Turtles, and Sea Birds observed during the field surveys.

Marine Fauna	**Fall 2005**	**Spring 2006**
Marine Mammals		
Bottlenose dolphin (*Tursiops truncatus*)	**(4)** *3 adults,1-junvenile*	**(22)** *19 adults,3 juveniles*
Rough-tooth dolphin (*Steno bredanensis*)	0	**(20+)** *15 adults,5 juveniles*
Atlantic spotted dolphin (*Stenella frontalis*)	0	**(5)** *4 adults,1 juveniles*
Sea Turtles		
Loggerhead turtle (*Caretta caretta*)	**2** (1dead)	**3**
Sea Birds		
Magnificent frigatebird (*Fregata magnificens*)	√	√
Royal tern (*Sterna maxima*)	√	√
Least tern (*S. antillarum*)		√
Caspian tern (*S. caspia*)		√
Eurasian collared-dove (*Streptopelia decaocto*)	√	
Osprey (*Pandion haliaetus*)	√	
Ring-billed gull (*L. delawarensis*)		√
Laughing gull (*Larus atricilla*)	√	√
Brown pelican (*Pelecanus occidentalis*)		√
Grackle (*Quiscalus quiscula*)		√

2005 Acoustic Monitoring for Marine Mammals

The passive acoustic monitoring system was deployed on October 5th and 6th for a total of 2 hours and 30 minutes during daylight and night. Due to strong winds and rough seas, observation conditions on October 3 were less than ideal. The weather improved for the following days and although the weather was favorable, no cetacean sounds were recorded during passive acoustic monitoring in 2005. Recording data logs appear in Appendix B.

Results of June 2006 Field Event

Protected species observations were conducted during daylight hours of June 14 – 16, 2006. Observations occurred on the deck during poor weather and above the wheelhouse to achieve a 360˚ view in good weather. A total of 31.96 hours of visual observation was completed for sea turtles, sea birds, and marine mammals. Twelve (12) sightings of protected species occurred. The most significant sightings were a pod of 20 or more rough-tooth dolphins (Figure 3-19), a pod of five Atlantic spotted dolphins, and three loggerhead sea turtles. Among the common sea bird species observed were the royal tern, magnificent frigatebird, brown pelican, and numerous gulls in the family Laridae

2006 Acoustic Monitoring for Marine Mammals

Acoustic monitoring was conducted between June 14 and 16, 2006 during daylight hours, to record marine mammal vocalizations. Acoustic monitoring was conducted for 15 minute intervals to record vocalizations. The hydrophone was deployed for a total of 2 hours and 19 minutes of acoustic monitoring. No cetacean sounds were recorded during the monitoring period.

Figure 3-19. Rough-Tooth dolphin (*Steno bredanensis*) observed June 15, 2006

4.0 POTENTIAL ENVIRONMENTAL IMPACTS OF DREDGING

4.1 Introduction

A review of dredging methods, equipment, and best management practices for dredging is provided below. Also the potential impacts of different dredging scenarios from the numerical modeling with respect to nearshore erosion and alteration of the shoals are discussed as they relate to the physical environment of the study areas and to the biological resources. Model test cases were examined to calculate potential near shore impacts from dredging different volumes of sand under normal and extreme weather conditions over time. Potential harm to biological resources is assessed for immediate affects that result from dredging and for the potential cumulative impacts that may occur.

4.2 Dredging Overview

4.2.1 Equipment

As described by W.F. Baird and Associates, Ltd. & Research Planning Inc (2004) and based on previous dredging projects conducted in Federal waters (including the dredging performed at T1 in early 2006), the most likely equipment of choice for offshore dredging for beach nourishment sand on MMS projects (i.e., in Federal jurisdiction areas at least 9 nautical miles off the Gulf coast in open water) will be the Trailer Suction Hopper Dredge (TSHD). Two TSHDs (Great Lakes Dredge and Dock Company's Sugar Island and Manhattan Island Dredge) with hopper capacities of 3,600 yd^3 were used for dredging at the T1 shoal in early 2006 (Coastal Planning and Engineering, Inc., 2006).

TSHDs are self-propelled ships suitable for operations in an ocean environment and capable of mining sand and loading a self-contained hopper while the ship is underway. Most TSHDs are twin screw and have bow thrusters, which provide a high degree of maneuverability. Loading takes place as the ship moves ahead at a speed of 2-3 knots. Unloading for beach nourishment projects is typically by pump discharge.

Using TSHDs provide the following advantages:

- performance in high sea state conditions with the use of heave compensated drag arms;
- independent operation without tender vessels;
- the ability to transport materials over long distance;
- the high rate of production; and
- operation in relatively deep water.

TSHDs are normally self-propelled ships that can travel between sites under their own power. A large proportion of the internal space of the TSHD is occupied by the hopper space into which the material is loaded by one or two large centrifugal pumps. The pumps are usually inboard but may be fitted into the trailing suction pipe (submerged pump). Submerged pumps are required for all deep water dredges. The suction pipe is stowed inboard when the ship is in transit between the dredging site and the discharge or off loading site. The maximum operating depth for a hydraulic dredge is determined by the vacuum head generated by the dredge pump. If the pump is mounted within the hull of the vessel, the maximum economical dredging depth is about 100 feet. By mounting the dredge pump externally in the trailing suction pipe, close to the draghead, a much greater dredging depth (up to 400 ft) may be economically achieved.

4.2.2 Operations

Most modern, high capacity dredges use suction produced by high speed centrifugal pumps to excavate the sediment and dispose of it, either through a pipeline or to a storage hopper. Material dislodged from the ocean floor by the suction is suspended in water in the form of a slurry and then passed through the centrifugal pump and discharge pipeline to the nourishment or disposal site. The types of dredges likely to be used in obtaining offshore sand for beach nourishment projects are cutterhead and hopper dredges. Hydraulic dredges have very high production rates when the materials to be dredged are relatively soft and contain a high ratio of water.

The trailer suction pipe with draghead attached is swung outboard and lowered using winches and davits. If inboard pumps are installed, the inboard end of the suction pipe is lowered in a fixed track to mate, below the waterline, with the pump suction intake, which is open in the side of the hull. Pipe works from the discharge side are routed to the hopper where discharge is conveyed to launders (chutes) to minimize turbulence. If the dredging pumps are located within the trailing suction pipe then there is a fixed connection of suction and pressure pipe systems.

The intake end of the suction pipe is fitted with a draghead, which strips off a layer of sediment from the seabed and entrain those sediments into the suction pipe. The draghead is lowered from the vessel proceeding forward at a speed from 1 to 5 knots. The bearing pressure of the draghead on the seabed is controlled by an adjustable pressure compensator system that acts between the draghead and the hoisting winch that supports the trailing pipe. This same system acts as a heave compensator that accumulates and smoothes out the vertical forces resulting from induced wave motions of the dredge. Because of this heave compensation, the TSHD can dredge effectively in much higher sea states.

The trailer suction pipes are usually located along port of the barge by means of an articulated link that supports a hose connection between adjoining lengths of rigid pipe. This articulation permits relative movement between the draghead and the vessel. As the vessel pumping continues, the sediment particles settle in the hoppers and the excess water passes overboard through overflow troughs. The percent volume of solids to water is generally around 15 - 20%. To reduce surface turbulence, overflow water is conducted along weirs and conveyed along the sides of the dredges opposite to where the dredged material is discharged into the hopper. In addition, to help reduce the effect of a surface plume the overflow is conveyed down along the side of the vessel hull to discharge below the waterline. This allows sufficient time for the particles to settle before overflowing.

The primary source of suspended sediment is the hopper overflow. Sediment suspended at the draghead is generally local and close to the bed. The hopper overflow usually produces a dynamic plume phase (where highly turbid water forms a turbidity plume or current through the water column), a passive phase and, sometimes, a near bed “pancaking” and laterally spreading turbidity current phase (W.F. Baird & Associates, Ltd & Research Planning Inc., 2004). “Pancaking,” describes the effect of the vertical momentum of the dynamic plume phase impacting the bed and with the subsequent transfer of this momentum to spreading in the horizontal plane (W.F. Baird & Associates, Ltd & Research Planning Inc., 2004).

With a maximum hopper size in excess of 35,000 m^3 TSHDs have highly accurate positioning and control systems, allowing them to be operated with considerable precision in the dredging area.

Two other developments in TSHD operations that have been adopted almost industry-wide are: (1) under hull release of overflow sediment (except for screening operations) and (2) the use of anti-turbidity valves (Tsurusaki et al., 1988; Pennekamp and Quaak, 1990; LaSalle et al., 1991). These operational changes reduce the extent of suspended sediment plumes generated by the overflow process.

4.3 Numerical Modeling of the Physical Environment

4.3.1 Introduction

The numerical modeling methods and simulations used in this report were based on the U.S. Army Corps of Engineers Research and Development Center (ERDC) Coastal Modeling System (CMS). The CMS was chosen for features that are consistent with the prevailing and dominant physical processes of the west Florida inner continental shelf. The geologic and physical features of the project areas were reviewed and are described in Section 2 of this report. Both the Siesta Shoal and T1/T2 regions are characterized by distinctive seasonal variations in circulation, winds, and wave energy. Seasonal variability of processes is punctuated by occasional tropical storms and extratropical storms associated with the passing of strong weather frontal systems. Predictable tides are then combined with these variable processes to complete the array of important physical processes that should be accommodated by the modeling system.

Based on the description of geologic features provided in Section 2, the shoal features consist of fine terrigenous (quartz dominated) sand and coarser carbonate material consisting of fossiliferous shells and rock fragments. For the shoal features that have minimum depth of 10 to 12 m at the crest, the most important processes likely to mobilize sediment are episodic storms that generate large waves. At the shoreline, waves and tide-produced currents associated with fair weather conditions may stir the fine sands that are typical of the beach and shoreface of the west Florida barrier islands. However, like the offshore shoals, the intense resuspension and transport of sediment over the upper shoreface and beach is associated with storms. Any modeling scheme applied to physical processes and morphologic changes across the inner continental shelf to the shoreline must account for all of the major physical processes. The following sections provide an overview of CMS capabilities to account for these physical processes and to justify using the CMS.

The strategy of physical modeling in the coastal waters off shore of west Florida is to apply the CMS to predict wave propagation, circulation, and related sand transport patterns before and after actual and hypothetical borrow cuts in selected shoal systems containing beach quality sand. An overview of each of the CMS modeling tools is provided in the following sections. The CMS was chosen for this project based on the record of accomplishment for successful applications in Federal projects and in private industry. Of particular importance to this project is the full wave-current interaction capabilities embedded in CMS and the powerful sediment transport model that is coupled with a module for simulating topographic change over time. The CMS has been developed over the past ten years (Buttolph et. al., 2006, Camenen et al., 2007) and is fully supported by ERDC through annual research budget for civil works from the U.S. Department of Defense. Examples of recent practical applications of the CMS in coastal settings include simulations in areas with complex topography near tidal inlets to manage sand resources, navigation, and dredging practices (Militello, 2002; Militello et al., 2003; Lin et al., 2004; and Zarillo and Kraus, 2007).

The capabilities of the CMS match or exceed those of similar modeling systems from the Danish Hydraulics Institute (DHI) and the Delft Hydraulics Laboratory designed for coastal engineering applications. Both the DHI and Delft modeling systems are available commercially but are considerably more expensive than the CMS. Currently the CMS is packaged in the Surface Water Modeling System (SMS), which is also supported by ERDC. The ERDC engineering tool, SMS, is available as a permanently licensed software platform from commercial vendors in the U.S.

The goal of the model simulation is to quantify the potential for significant physical influence at and near the shoreline as a consequence of dredging large volumes of sand in the study areas. The results of the model simulations are presented with respect to wave patterns, littoral transport near the shoreline, and predicted topographic changes on the shoreface in littoral water depths. Model results represent the conditions before and after dredging of single sand borrow cuts and after large dredge cuts in the shoals designed to simulate removal of sand from the borrow sites for multiple beach fill projects. Table 4-1 summarizes the model test cases that were performed in each of the study sites.

Table 4-1. Summary of Model Test Cases.

Model Test	**Location**	**Borrow Cut**	**Volume**	**Test Duration**
Case1	T1/T2 Shoals	None	N/A	2 years
Case 2	T1/T2 Shoals	Single	600,000 m^3	2 years
Case 3	T1/T2 Shoals	Multiple	7 million m^3	2 years
Case 4	Siesta Shoal	None	N/A	2 years
Case 5	Siesta Shoal	Multiple	2.3 million m^3	2 years

4.3.2 Numerical Modeling Methods

A numerical model simulation, CMS, was applied to quantify the potential impacts of sand excavation from the T1, T2, and Siesta Shoals in Federal waters off the west coast of Florida (Figure 4-1). The CMS is a coupled group of numerical models for calculating waves, circulation, sediment transport, constituent transport, and morphology change. Calculations can be performed for flows generated by tide, wind, waves, river discharges, and changes in salinity. The CMS was developed under the Coastal Inlets Research Program (CIRP) conducted at CHL for Headquarters, U.S. Army Corps of Engineers.

During the MMS west Florida shelf study, a wave model (CMS-WAVE) and a two-dimensional vertically averaged circulation model from the CMS (CMS-FLOW) were combined. The wave model was driven by a combination of hind cast data and wind stress for local wave generation. Boundary conditions to drive the circulation and sediment transport model included time series of water elevation distributed along the ocean boundary, forcing from the wave model, and wind speed and direction. In operation, the wave model was

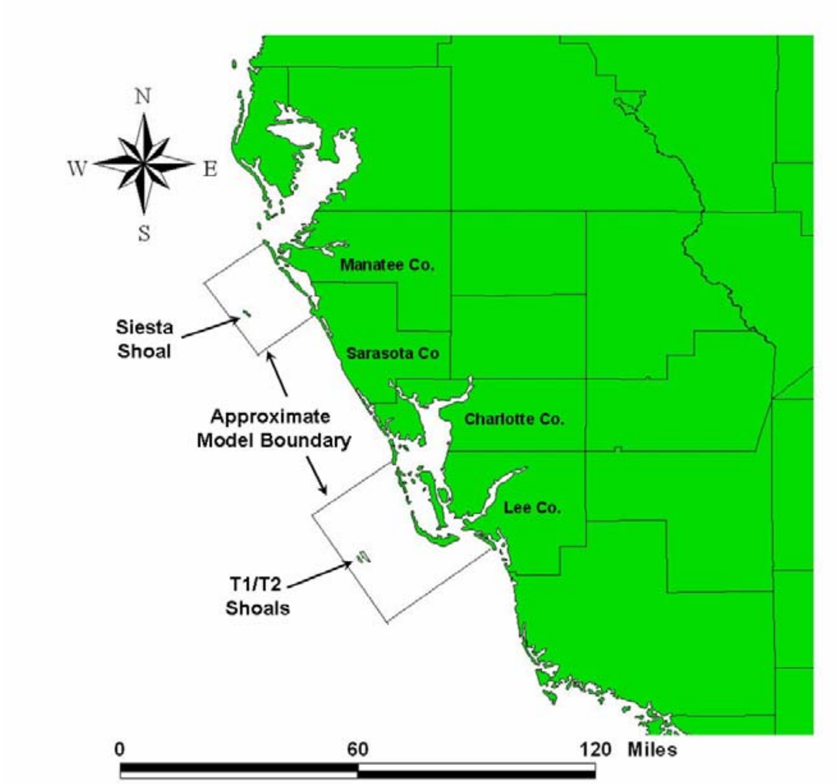


Figure 4-1. Location of the T1, T2, and the Siesta Shoals in Federal waters offshore of west Florida. The approximate boundary of each model is also shown.

run to force the circulation and sediment transport models as well as to provide predictions of wave heights over the study area. Once the wave field was predicted, the resulting forces were combined with wind to drive the circulation model. The circulation model included sub-models to predict sand transport and erosion.

The combined wave, circulation, sand transport, and topographic change modeling scheme was run for the calendar years 1998 through the end of 1999. This period was chosen because it corresponds to the most recent period from which adequate wave hind cast data are available from the U.S. Army Corps ERDC Wave Information System (WIS) described under section 2.5.4. Results of the model runs were compared to determine predicted changes in wave patterns, sand transport patterns, and net topographic changes on the shoreface on both a regional and local basis with respect to the proposed sand borrow sites. The following sections provide the details of model setup and results of the model simulation.

4.3.3 Wave Model

The wave simulation model now termed CMS-WAVE, is based on the Wave-Action Balance Equation with Diffraction or WABED, is a steady-state, spectral, finite-differencing model that simulates wave shoaling, wave refraction, wave breaking, and wave growth due to wind. The WABED model (Mase and Kitano, 2000; Mase et al., 2005) follows the STWAVE model (Smith et al., 1999) as a new generation wave model developed for ERDC to couple with 2- and 3-dimensional hydrodynamic models designed for predictions in coastal waters. CMS-WAVE uses a forward-marching, finite-difference method to solve the wave action conservation equation. The capabilities of CMS-WAVE include wave shoaling, refraction, diffraction, forward reflection, depth-limited breaking, dissipation, and wave-current interaction. Wave diffraction is implemented by adding a diffraction term derived from the parabolic wave equation to the energy-balance equation. CMS-WAVE also includes prediction of local wind-wave growth, and white capping to redistribute and dissipate energy in a growing wave field.

For the analysis of the potential effects from borrow cuts on the T1, T2, and Siesta Shoal borrow cuts, CMS-WAVEwas coupled with the CMS-FLOW circulation and transport model to resolve wave radiation stresses and currents due to wave interactions. A two-way interaction between the circulation model and the wave model allowing the circulation model to be updated using the wave stresses and wave-current interactions computed by CMS-WAVE. The wave calculation was also updated using changes in topography and wave-current interactions. CMS-WAVE includes options for frictional energy dissipation in shallow water and energy reflection at the shoreline and coastal structures.

4.3.4 Circulation Model

CMS–FLOW provides tide, wave, and wind driven currents and sediment transport predictions. CMS-FLOW is a finite-volume circulation and sediment transport model that solves the 2D continuity and momentum equations as well as the sediment continuity equation (Buttolph et al., 2006). CMS-FLOW has recently been updated to apply an implicit calculation approach for solution of the hydrodynamic equations. This advancement enables rapid computation of water level and current velocity. CMS-FLOW calculates current velocity and water level at each hydrodynamic time step. First developed at the Florida Institute of Technology in 1994, CMS-FLOW has been maintained and upgraded by the Coastal Hydraulics Laboratory (CHL) of the U.S. Army Waterways Experiment Station (WES) over the past decade. A newer feature of CMS-FLOW relevant to the project is the ability to include hardbottom areas in the grid that can represent shore protection structures, reef rock outcrops, and artificial reefs. During model calculations, the spectral wave model interacts with the circulation model by passing wave produced radiation stresses and orbital velocities to the circulation model at user specified intervals. Similarly, current information can be sent back to CMS-WAVE to provide full current-wave interaction between the models, which is an important process in shallow nearshore areas dominated by waves and tides.

4.3.5 Sand Transport and Topographic Change Calculations

The simulation of sand transport is based on a submodel in the CMS-FLOW model code. Developed for CHL of the U.S. Army Waterways Experiment Station at Lund University in Sweden, the sand transport subroutine is called the "Lund Formulation". The Lund Formula considers processes that can be important in shallow water under the influence of waves. Processes in the formulation relevant to dynamics of shoal features in the coastal ocean include bed load and suspended load, waves and current interaction, breaking and non-breaking waves, slope effects, initiation of motion, asymmetric wave velocity and arbitrary angle between waves and current. The Lund Formulation incorporates the developments in sediment transport technology from the past 50 years. The emphasis of the Lund Formulation is on reliable predictions over a wide range of input conditions. All relevant physical processes were incorporated to obtain greatest application to the coastal and nearshore environments including (1) bed load and suspended load, (2) waves and currents, (3) breaking and non-breaking waves, (4) bottom slope, (5) initiation of motion, (6) asymmetric wave velocity, and (7) arbitrary angle between waves and current. The development of the Lund Formulation relied on a large database of sediment transport measurements made in the laboratory and the field and compiled to test different aspects of the formulation over the widest possible range of conditions. The performance of Lund Formulation was compared to several popular existing predictive formulas, and the Lund Formulation yielded the overall best predictions among the formulas investigated. The derivation details of the formulation, with a listing of the equations that comprise the Lund Formulation can be found in Camenen and Larsen (2005, 2006, and 2007).

Topographic change is calculated from the predicted flux of sand movement through the model grid cells. The sand transport formulation provides predictions of sediment flux through the sides of each grid cell and the topographic change at each time step is calculated according to a sediment continuity formulation that relates the change in topographic elevation to spatial and temporal flux of sand. Details of the sediment continuity can be found in Buttolph et al. (2006).

4.3.6 Model Grids and Boundary Conditions

The CMS as applied to the MMS projects sites includes separate computational grids for the wave model calculation and for the CMS circulation model. The wave model grid resolution was 50 meters, whereas the resolution for the circulation model included variable cell sizes between 200 and 50 m in a Cartesian grid. Separate applications of the CMS were applied to the Siesta Shoal and the combination of the T1 and T2 Shoals. Figure 4-1 shows the location of the model domains for each application off the west Florida coast.

In model runs, calculations of wave forcing were completed on the wave model grid and interpolated onto the circulation model grid, alternating the use of the two models under a model steering module of the Surface Water Modeling System (SMS). Forcing for the wave model was provided by a time series of directional wind data from coastal meteorological station in northeast Florida and with NOS data from Station NPSF1 in Naples and Station FMRF1 in Ft Myers. Spectral wave forcing data correspond to 1998-1999 conditions and were obtained from the ERDC Wave Information System (WIS).

The wave climate and seasonal variability in the wave regime was reviewed in detail within Section 2.5.3. The analysis of the west Florida wave climate was based on hind cast data from WIS stations 490 and 472, which were used to force the CMS wave model in the vicinity of the T1 and T2 shoals and the Siesta Shoal, respectively.

When wave data are applied to force the wave model, the spectral features of the wave field are set according to the water depth at the model boundary and according to the wave period. Figure 4-2 is an example of the wave spectral energy distribution by direction applied to force the wave model in the T1/T2 Shoal area. This particular spectrum represents storm-generated waves in early February 1998. Figure 4-3 shows the topography included in both the wave and circulation models, the location of shoals T1 and T2, and the location WIS Station 490 used to assemble spectral wave forcing.

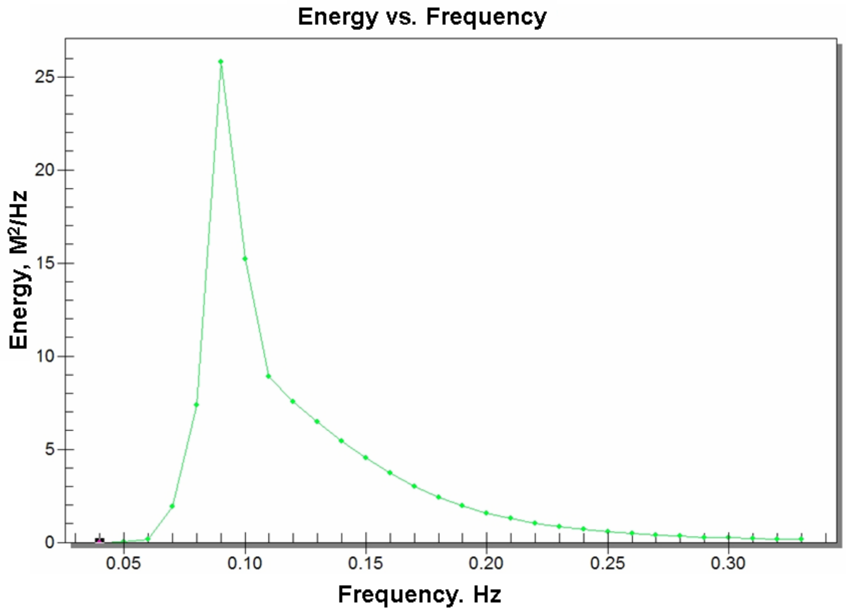


Figure 4-2. Spectral wave energy by direction for storm conditions in early February 1998.

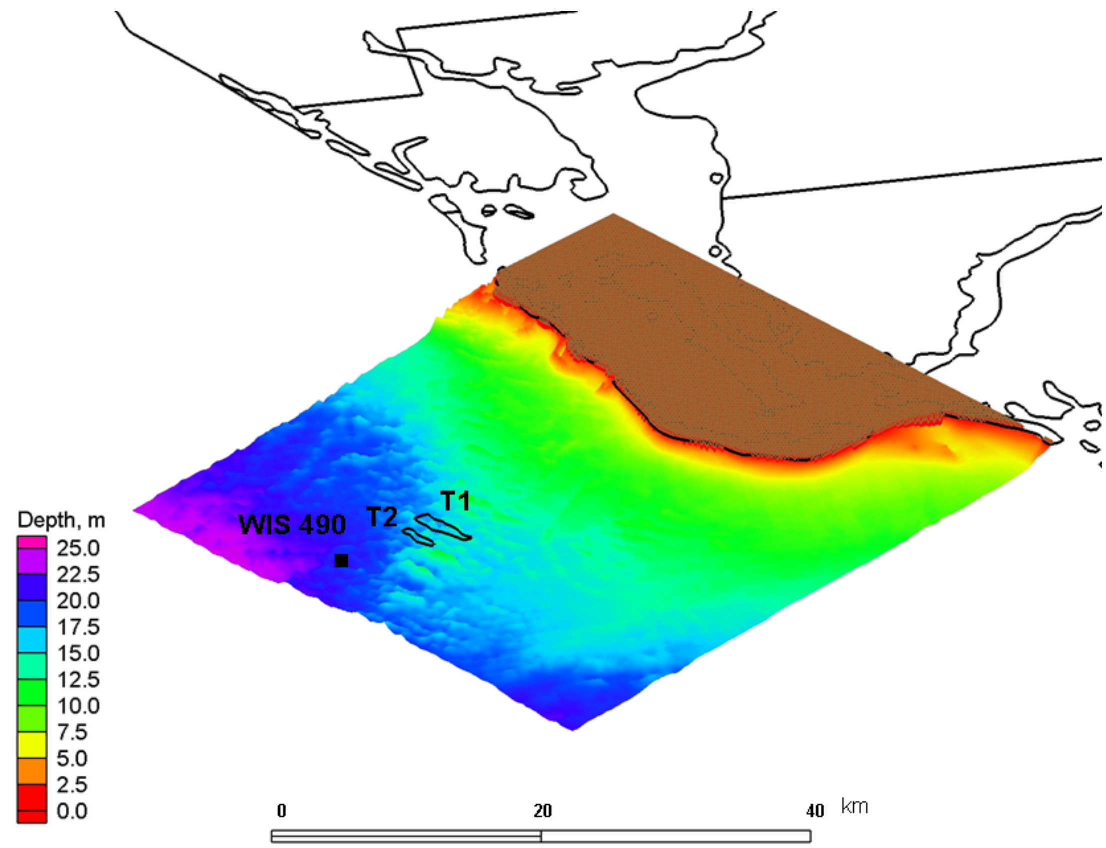


Figure 4-3. Location and bottom topography near the T1/T2 Shoals system. WIS station 490 is shown at the seaward boundary of the model domain.

In addition to waves, forcing for the CMS circulation model, including sediment transport calculations, was from a combination of predicted tides along with a subtidal or low frequency water level time series obtained by digital filtering of data from NOAA coastal water level stations. The tidal signal for each boundary cell in the M2D model was extracted from the East Coastal Tidal Data Base (Mukai et al., 2001) created for the U.S. Army Coastal and Hydraulics Laboratory for coastal modeling. The tidal regime and examples of tidal constituents from East Coastal Tidal Data Base system are reviewed in section 2.5.1 of this report (see Figure 2-20). A water level oscillation time series based solely on constituents from the database was extracted for each cell boundary cell in the model grid. Then a low frequency signal acquired from the nearest NOAA coastal station by filtering off the tidal signal was added to each time series of tidal data. For the T1/T2 shoal system, the nearest NOAA station is located near Naples, FL, whereas for the Siesta Shoal area offshore of Sarasota County, the nearest NOAA station is located near Clearwater, FL.

The model boundary conditions combine both the tidal forcing and lower frequency sea level oscillations. Because there is little spatially dense measured data in the study areas, this method is considered the most accurate way to represent boundary conditions in a model domain within the coastal ocean. Figure 4-4 shows the circulation model grid, boundary cell-string where water level forcing is applied, and a series of numerical observation stations along the shoreline to record predicted time series of water level, flow, and sand transport rates.

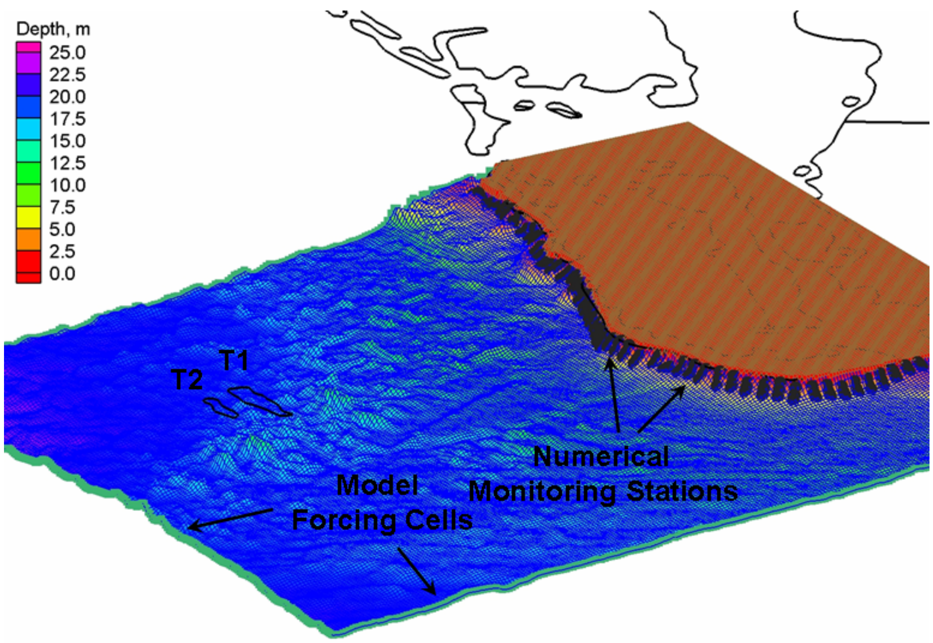


Figure 4-4. Circulation model grid, model forcing cells, and location of numerical monitoring stations at the shoreline.

4.3.7 Wave Model Calibration

It is important to evaluate the performance of the CMS wave model since modification of wave patterns over the shoals and possible related changes to the wave field at the shoreline will be largely responsible for potential impacts from excavation of borrow sites on the shoals. Wave model predictions are based on boundary conditions derived from the USACE Wave Information System (WIS). Because the WIS data are hind cast, it is necessary to quantify the skill of model predictions where possible to be sure that the model predictions are reasonably accurate.

The performance of the CMS wave model was evaluated by comparing predicted and measured wave data for a nearshore location just offshore of Sarasota. The CHL maintained a directional wave gauge (Station F002) from 1993 through a portion of 1996. Since this location is within the model grid for the Siesta Shoal, regional data from this directional gauge allows validation of predicted data from the CMS. The approximate location of the gauge (F002) moored in 8 m of water is shown in Figure 4-5.

Predicted wave height data were extracted from the cell containing the position of the F002 directional gauge and compared with measured wave data for the period from January 1995 through June of 1996. Similar to the model predictions of conditions around Siesta Shoal in 1998-99, boundary conditions for the wave model calibration run were extracted from WIS hind cast Station 272 offshore of the shoal. Figure 4-6 shows the comparison between January 1, 1995 and late June 1996 when the gauge was removed. Figure 4-7 shows the details of the comparison between late October 1995 and early February 1996. Statistically the root mean square (RMS) difference between the predicted and measured data is about 6 cm (about 2.3 in.), whereas the mean error (ME) is about 5 cm (about 2 in.). Thus, the predicted data slightly overestimates the measured data but the model is considered to be well calibrated with respect to the measured data. Also, the measured data are from a precise location within a grid whereas the predicted data represents an entire grid cell.

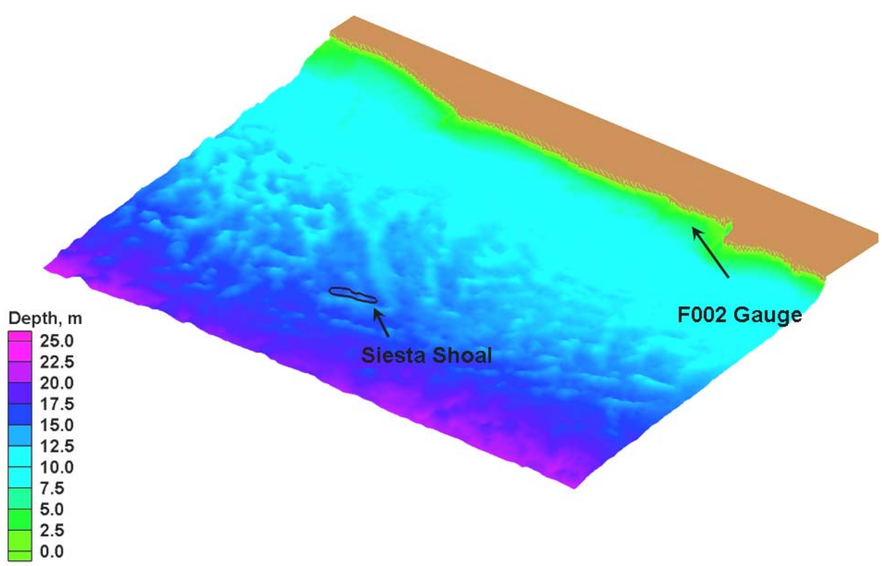


Figure 4-5. Perspective view from the southwest showing the location of Siesta Shoal and the location of the USACE F002 direction wave gauge used to verify wave model results. Vertical exaggeration is 200x.

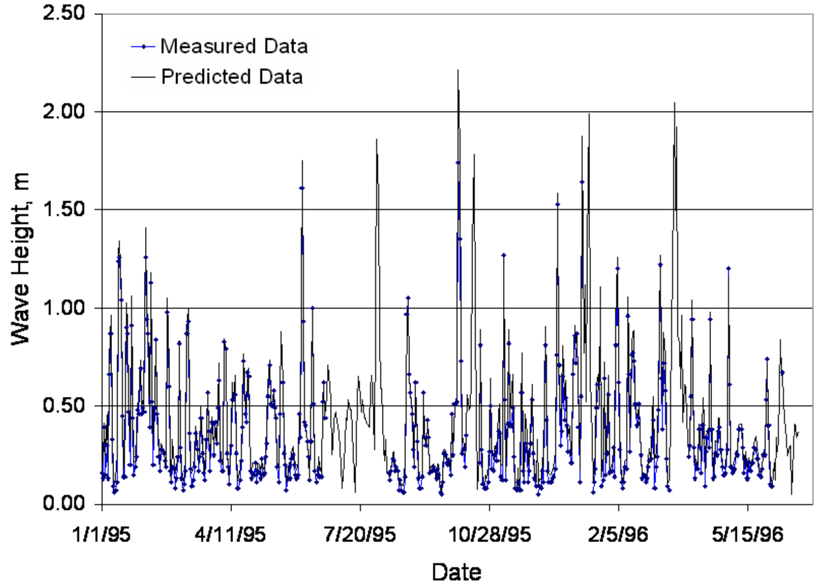


Figure 4-6. Siesta Shoal: Comparison of predicted and measured wave height data at ERDC Station F002 from January 1995 through May 1996. Statistical comparison included a RMS error of 0.06 m and ME of 0.05 m. Refer to Figure 4-5 for the location.

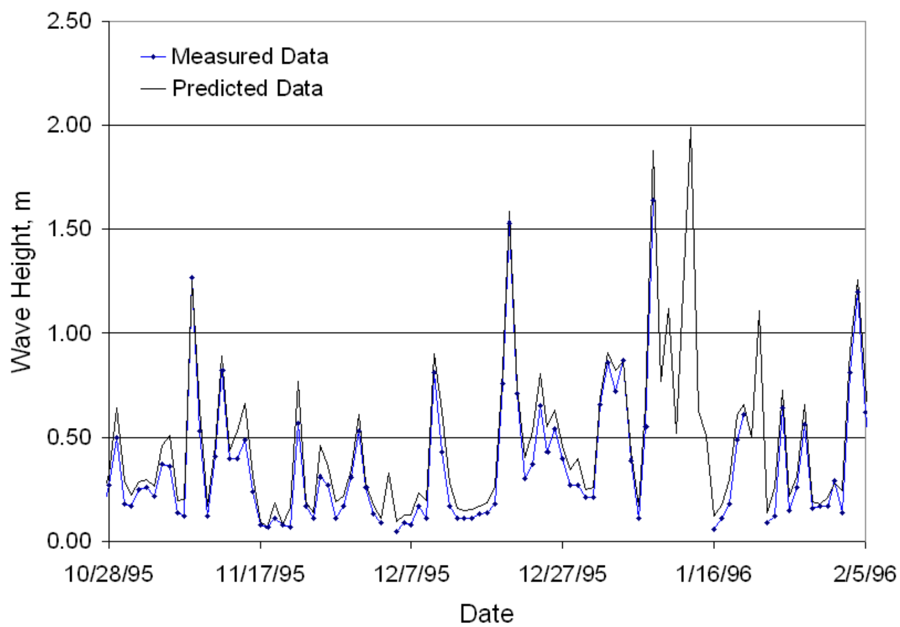


Figure 4-7. Details of the comparison of predicted and measured wave height data at ERDC Station F002 between October 1995 and February 1996.

4.3.8 Model Results: Tom's Hills Shoal System

Predicted Changes in Wave Patterns

Figure 4-8 shows the design of the borrow cut in the T1 Shoal completed in 2006 that excavated approximately 600,000 cubic yards of sand and barged approximately 30 miles to the southwest for a beach fill project in the vicinity of Naples in Collier County, FL. The borrow cut reduced the elevation within the T1 shoal to between -13 to -16.5 m (-45 to -54 ft NGVD). Prior to the cut, the maximum elevation of the shoal surface reached approximately -11.5 m (about -38 ft NGVD). Figure 4-9 shows the representation of the borrow cut in the wave model grid. Geotechnical studies in support of the permit application for the current T1 borrow cut along with results of recent surficial sampling of both shoal features indicate that the T1/T2 shoal system contains several million cubic yards of beach quality sand (CPE, 2005). Thus, in order to consider the influence of larger and multiple borrow cuts in the T1/T2 shoal system additional modifications were made to the wave and circulation model grids. Figure 4-10 shows a perspective view of more extensive hypothetical borrow cuts in T1 and T2. The total volume of sand removed represented by the hypothetical cuts is approximately 9 million cubic yards or about 7 million cubic meters. The elevation of each shoal was reduced by 2 to 4 m.

Analysis of the predicted wave regime with and without the borrow cuts in the T1 and T2 shoals indicates the most apparent differences will occur during storm conditions. Long period waves propagating across the shoals and borrow areas are predicted to be influenced by the altered shoal topography compared to predictions over the unmodified model grid topography. Figure 4-11 shows the wave propagation pattern over the model area predicted for extreme wave conditions in early February 1998. During this storm-produced event, offshore wave heights reached a maximum of approximately 4 m (13 ft) at a wave period of 11 s. Although the crest of the T1/T2 system is below a depth of 10 m, the wave period and associated wavelength was long enough for waves propagating across T1/T2 to be influenced by the shoal system topography.

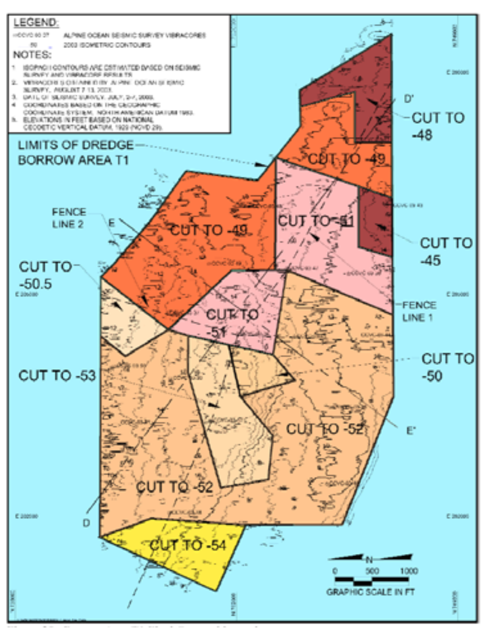


Figure 4-8. Permit design of the borrow cuts at the north end of the T1 Shoal (from CPE, 2005). (Note position of north arrow).

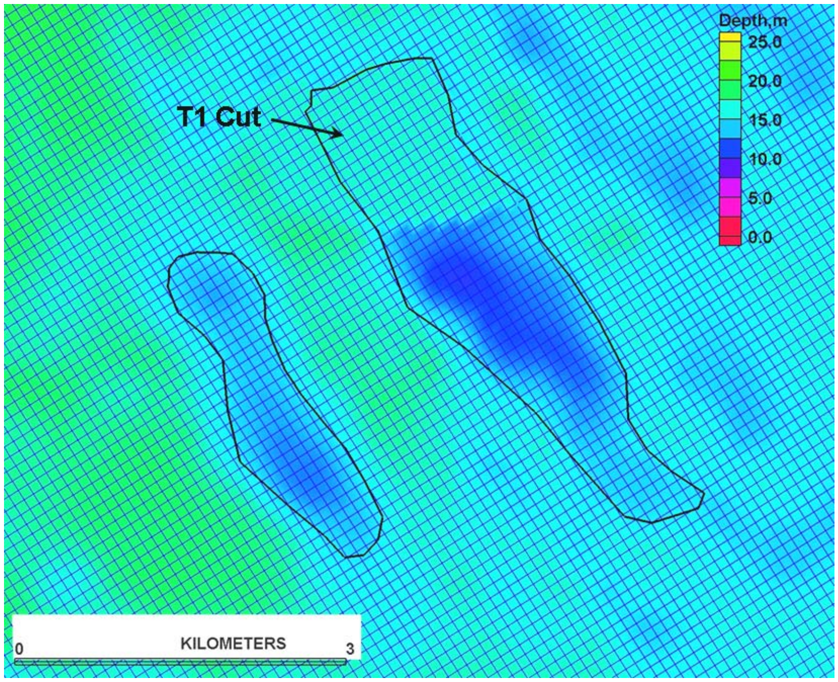


Figure 4-9. Representation of the existing 2006 borrow cut in the T1 Shoal within the wave model grid.

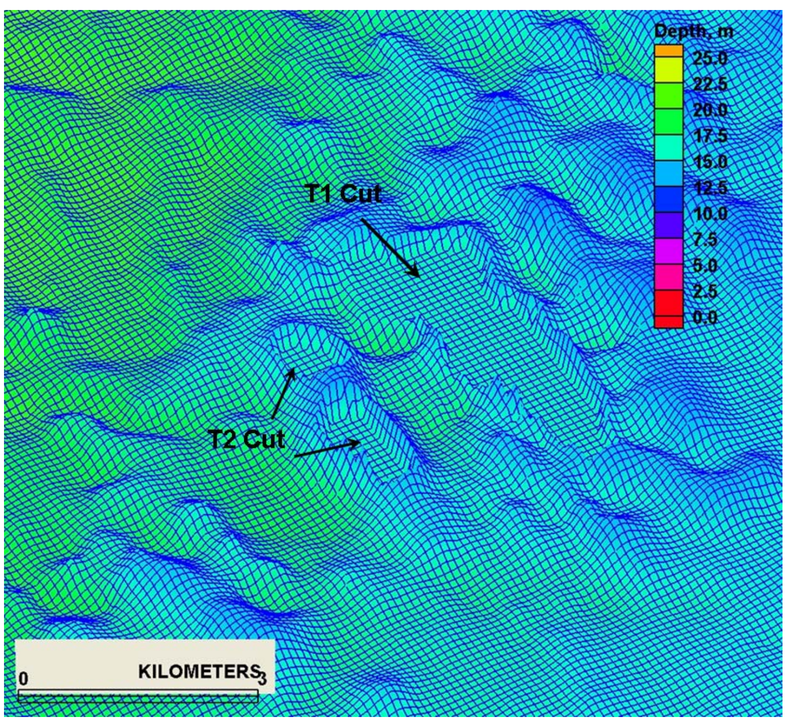


Figure 4-10. Perspective views from the southwest showing the extensive hypothetical borrow cuts in the T1/T2 shoal system that would remove approximately 2.3 million cubic meters of sand.

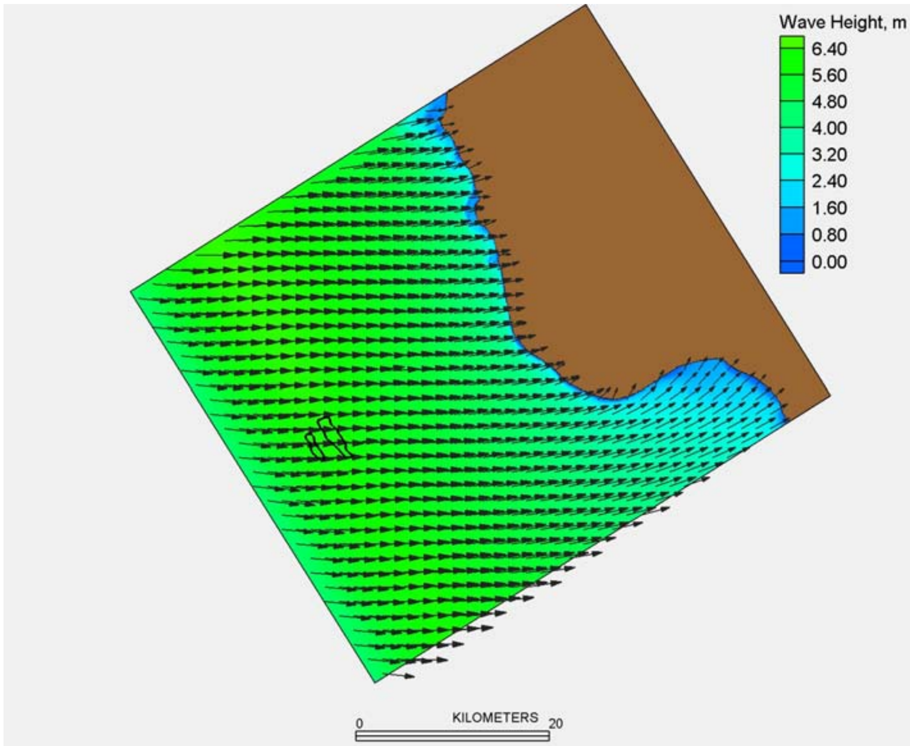


Figure 4-11. Wave propagation pattern over the T1/T2 wave model grid during storm produced high wave energy conditions in February of 1998.

Strong wave refraction in the nearshore and littoral zone where waves begin to break can be seen in Figure 4-11 as waves propagating toward the shoreline undergo the shoaling transformation and break in the surf zone. Refraction effects over the crest of T1/T2 are most noticeable when comparing wave propagation before and after the borrow cuts are placed in the wave model grid. Figure 4-12 compares wave patterns over the original topography with predicted wave patterns after the most extensive borrow cut is in place. Refraction effects are only measurable in the model simulations under relatively long period and high wave conditions that can be produced by storms in the Gulf of Mexico.

Figure 4-13 shows the predicted difference in wave height across T1/T2 after the 2006 borrow cut (Panel A) was placed in the wave model grid. Panel B represents the predicted net change in wave height after the more extensive cumulative cuts were placed in the wave model grid. The wave conditions shown are for the winter 1998 event in which hind cast waves off the west Florida coast reached 4 m at a period of approximately 11s. In both cases, measurable changes in distribution of wave height across the shoal system are predicted. In the case of the single cut representing the 2006 excavation in the T1 shoal, wave height over the borrow area was predicted to increase by up to 30 cm or about 1 ft, whereas the areas flanking the cut were subject to a reduction of wave height of up to 10 cm (about 0.3 ft). The detectable influence of the cut on wave height reduction was predicted to extend to the east of the shoal system by approximately 10 km (approximately 6 miles). Beyond this distance, the predicted changes in wave height were reduced to zero. For the larger excavation representing multiple borrow cuts, the predicted pattern of change shows an increase in wave height across both the T1 and T2 shoals relative to the 2006 single borrow cut. The cumulative effect of larger, deeper excavation areas with multiple borrow cuts resulted in an increase in wave height across a broader area of the two shoals. In other words, multiple borrow cuts

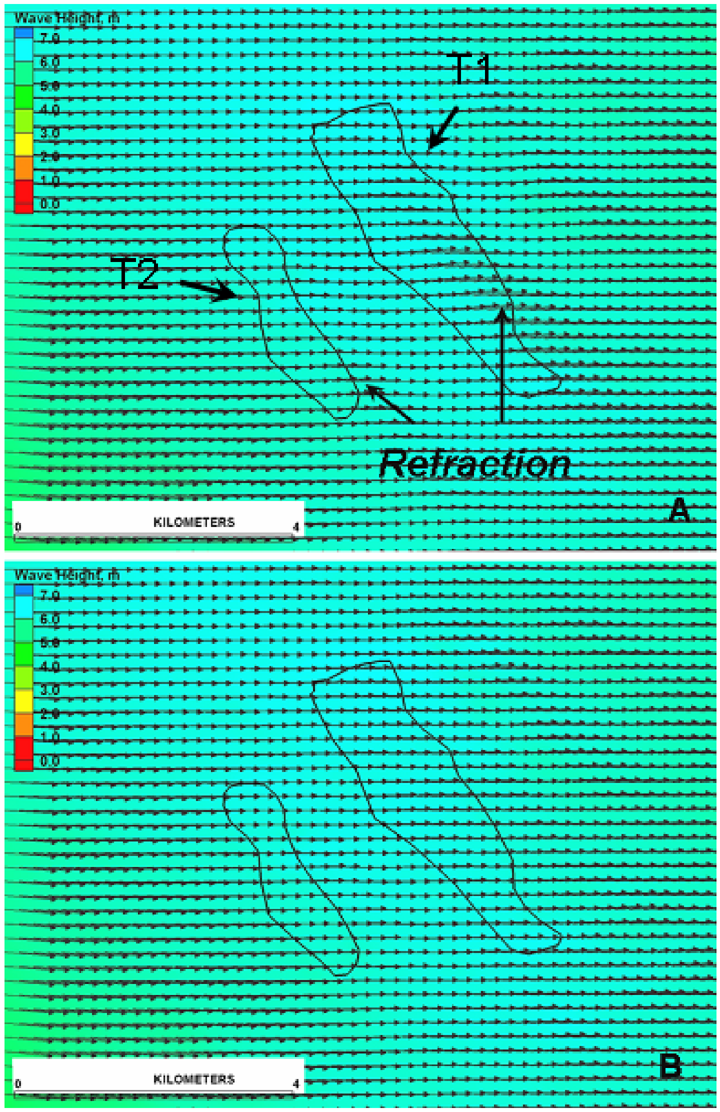


Figure 4-12. Wave refraction of the T1/T2 Shoals apparent over the pre-borrow cut topography (A) during an extreme wave event. Predicted refraction is minimal during the same event over the post borrow topography (B) that includes large cuts in both shoals (see Figure 4-10.

are predicted to reduce the shoaling effect over the shoals to a greater degree than with the single borrow cut. Over the west portion of the T1 shoal wave heights are predicted to increase between 20 and 44 cm (about 0.6 to 1.4 ft) due to the larger excavation area compared to the T2 shoal predicted wave height increases of between 20 and 30 cm (about 0.6 to 1 ft) due to the smaller excavation area. In the adjoining areas of the T1/T2 shoal system, wave height reductions are predicted to vary from near zero to a maximum of 20 cm (0.6 ft). Similar to the case of the single borrow cut, the detectible influence of multiple borrow cuts on wave height reduction was predicted to extend to the east of the shoal system by approximately 10 km.

Tropical systems often affect the west coast of Florida creating high wind and wave conditions along with storm surge. For instance in the 1999 model period, the maximum hind cast wave conditions in the eastern Gulf of Mexico occurred between September 19th and 22nd when Tropical Storm Harvey tracked

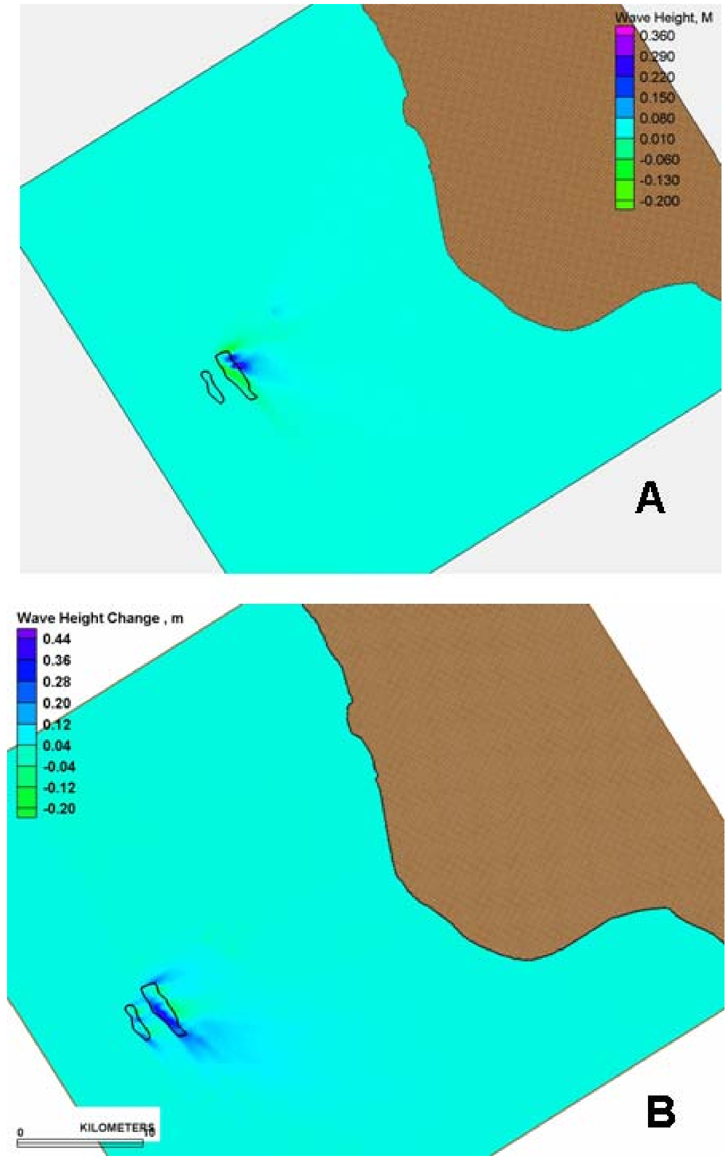


Figure 4-13. Predicted difference in wave height during the 1998 winter storm after excavation of the 2006 borrow cut in Shoal T1 (Panel A) and after excavation of multiple borrow cuts in T1 and T2 (Panel B).

to the east crossing south Florida between September 21st and 22nd. Harvey made landfall near Everglades City south of the study area with sustained winds of 50 knots and a minimum central pressure of 999 mb. Hind cast wave data for this period indicates that wave heights along the west boundary of the model grid would have been in excess of 10 feet and propagated to the north in the areas of the T1/T2 Shoal system. Figure 4-14 shows the predicted regional wave height pattern and direction of propagation for these conditions. Figure 4-15 shows that when moving northward across the shoal system a noticeable refraction pattern occurs as the wave travels at slight angle to the long axis of the shoal system.

Figure 4-16 compares the predicted influence on wave height due to the cumulative borrow cuts placed in the shoal topography. In this case, predicted increase in wave height across both shoals reached a maximum of about 18 cm (about 0.35 ft) along with decreases in height of the same magnitude largely

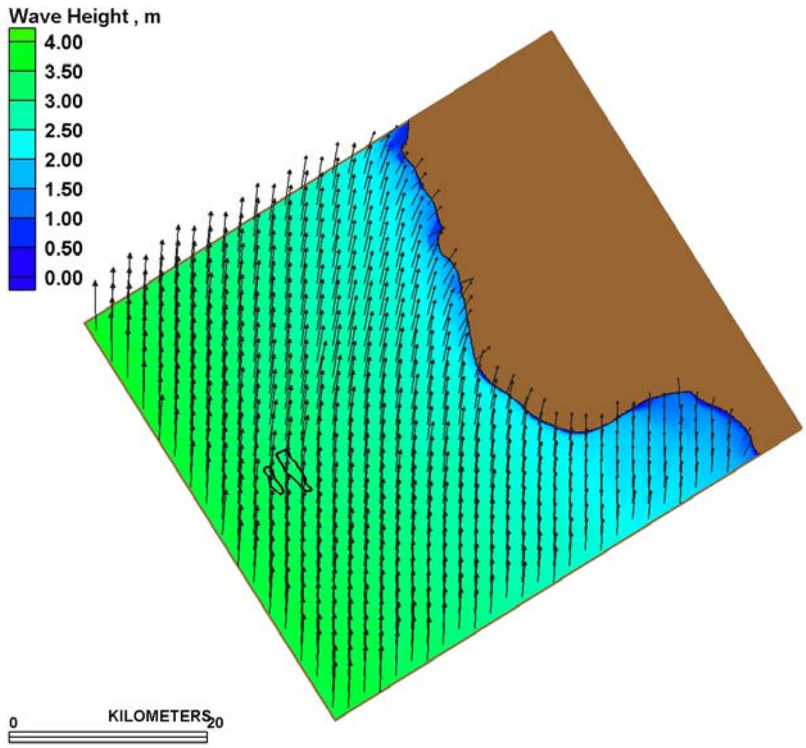


Figure 4-14. Regional wave pattern over the T1/T2 shoal system resulting from the passage of Tropical Storm Harvey in September 1999.

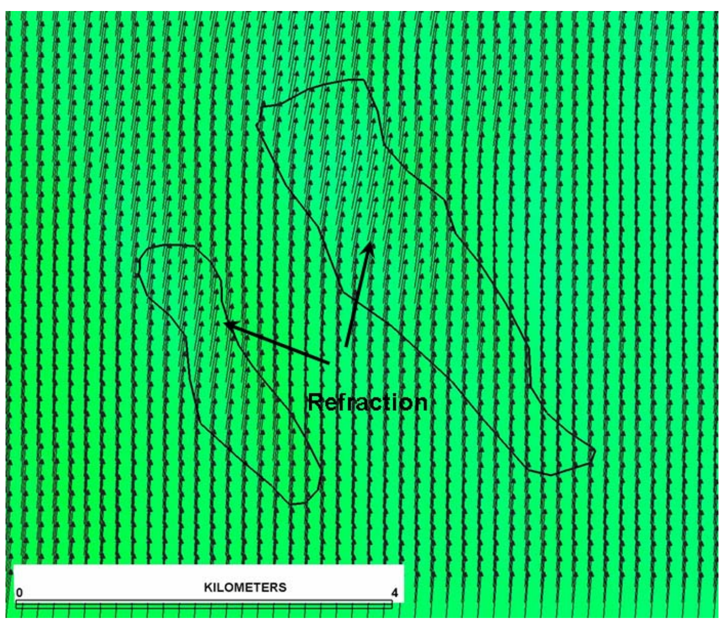


Figure 4-15. Predicted refraction pattern as waves move northward and diagonally across the T1/T2 Shoals during Tropical Storm Harvey in September 1999.

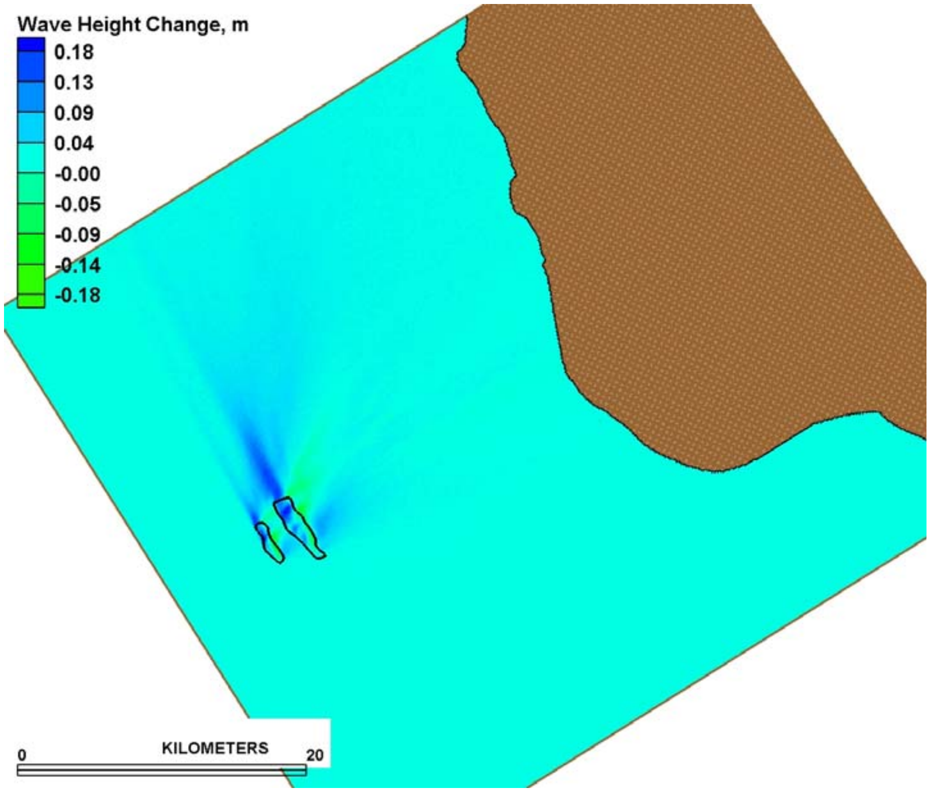


Figure 4-16. Predicted change in wave height patterns after the T1/T2 topography is modified by multiple borrow cuts. Wave conditions in the simulations are associated with the passage of Tropical Storm Harvey in September of 1999.

confined to the east side of the borrow cuts. Unlike the case for the 1998 winter storm in which the influence of the borrow cuts on wave patterns was transmitted to the east for 10 km, for Tropical Storm Harvey the influence of the cuts on wave patterns was transmitted to the north up to a distance of 20 km north of the shoal system. The influence of the borrow cuts on the wave field propogated by Tropical Storm Harvey was also transmitted to the northeast and east of the shoals due to the regional refraction pattern of wave energy as shown in Figure 4-13. However within about 5 km of the shoreline the influence decreases to near zero compared to the wave patterns associated with the pre-borrow cut topography.

Overall, the wave modeling shows that excavation of the T1 and T2 shoals, with waves approaching from the west, would likely produce relatively large differences in wave height patterns locally within and around the shoal system. However, the shallow waters east of the shoal system and irregular topography will likely mask and overwhelm the influence of borrow pits within a distance of about 10 km to the east of the shoal system and well offshore of the coastline. On the other hand, when waves approach from the south, the influence of borrow pits can be transmitted well beyond 10 km as wave energy continues to propagate in relatively deep water. Wave energy also refracts to the east-northeast as shown in Figure 4-14 carrying the influence of the excavation toward the shoreline. However, the influence on wave height drops to less than 1 cm within 2 km the shoreline and is almost undetectable at the shoreline.

Predicted Sediment Transport Rates

Figure 4-17 shows an example of the predicted regional velocity field from the model simulation for two storm periods: February 4, 1998, which corresponds to the 1998 winter storm, and September 21, 1999 which corresponds to Tropical Storm Harvey. Higher energy storm events were selected to illustrate regional circulation and sand transport patterns since wave- and current-generated sediment transport beyond the shoreface is weak under most wave and wind conditions. However, under higher energy storm conditions, portions of the inner shelf can be subject to sediment transport. The most intense transport is predicted to be in the nearshore and surf zone as shown in Figure 4-17 for the February 1998 winter storm in the eastern Gulf of Mexico (Panel A) and the impact of Tropical Storm Harvey in September of 1999 (Panel B). Maximum velocity magnitude in the model area occurs within the surf zone where breaking waves drive longshore currents up to 50 cm/s (about 1.6 ft/s). Figure 4-18 shows the details of the current field in the nearshore and littoral zone. In the case of the February 1998 winter storm, which produced wave periods as long as 11s in the nearshore area, the surf zone was wider due to initial breaking of these long period waves several hundred meters offshore (Figure 4-18, Panel A). In the case of Tropical Storm Harvey, the wave periods were produced over a more limited fetch area and reached a maximum of about 8 s (Figure 4-18, Panel B). Thus, the predicted surf zone was somewhat narrower.

The predicted sand transport rates are presented on an annualized basis for ease of interpretation in Figure 4-19. Predicted sand transport rates for the 1998 winter storm were larger than the rates predicted for the Tropical Storm Harvey in 1999. When annualized, the 1998 winter storm event would produce total littoral transport rates of 1 to 4 million cubic meters per year, whereas the extrapolated rates for Tropical Storm Harvey would produce sand transport rates in the littoral zone on the order of 200,000 to 500,000 cubic meters per year moving through a particular model cell.

The sum for all net sand transport annulized rates are predicted to range from a few thousand to about 50,000 cubic meters. The combination of sand transport rates from episodic storm induced events with intervening fair weather conditions form the annual net sand budget.

Although the results of wave model simulations indicate that the influence of topographic modifications to the T1/T2 shoal system are minimal at the shoreline, it is important to examine the sand budget in the littoral zone with and without the permitted and hypothetical borrow cuts in place. There were 66 numerical monitoring stations established in the littoral zone at intervals of approximately 1 km. Each monitoring site consisted of three to four stations distributed across what is considered the surf zone and the very nearshore environment in order to capture all possible components of longshore sand transport including littoral currents. Figure 4-20 shows the position and identifying number for the numerical monitoring stations along the coast within the model. Figure 4-21 shows the configuration of the numerical monitoring stations in the littoral zone of Sanibel Island along the southern portion of the model domain. Over the course of a model run the instantaneous rates of predicted longshore sand transport were recorded at hourly intervals and then integrated over the 2-year model period.

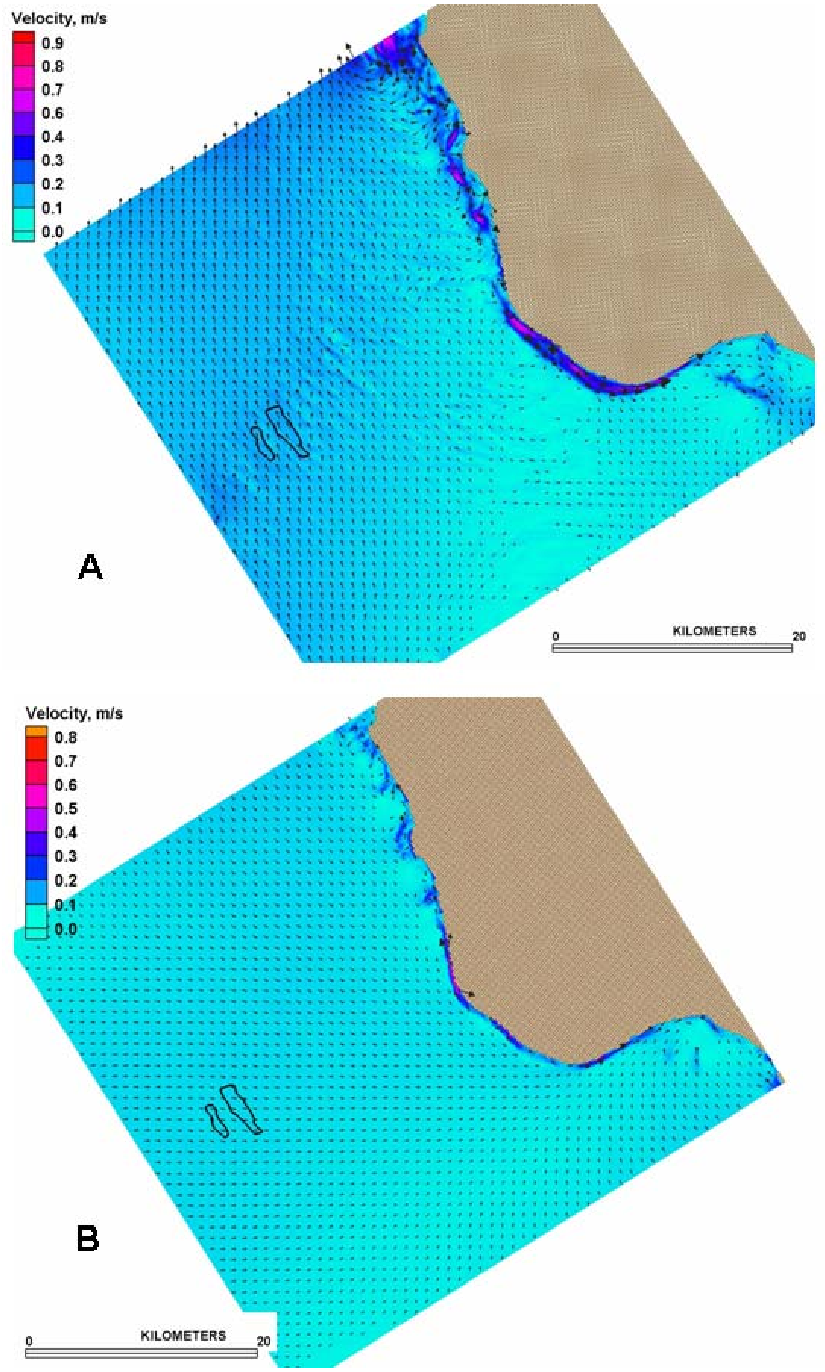


Figure 4-17. Regional velocity field generated from the T1/T2 model during winter storm in February 1998 (A) and Tropical Storm Harvey in September 1999 (B).

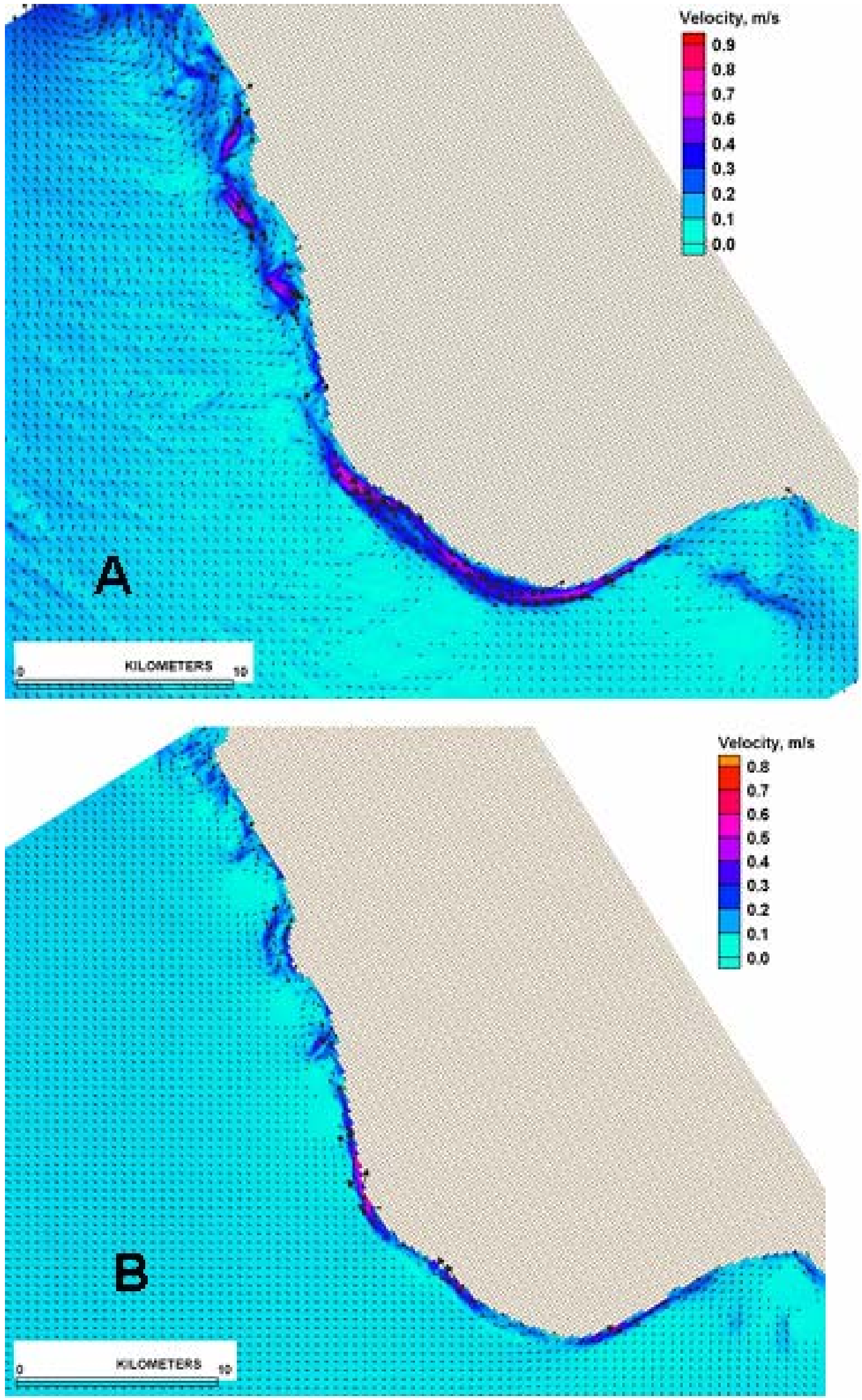


Figure 4-18. Details of predicted littoral zone longshore currents for the T1/T2 model generated by breaking waves for the Winter Storm of 1998 (A) and Tropical Storm Harvey in September 1999 (B).

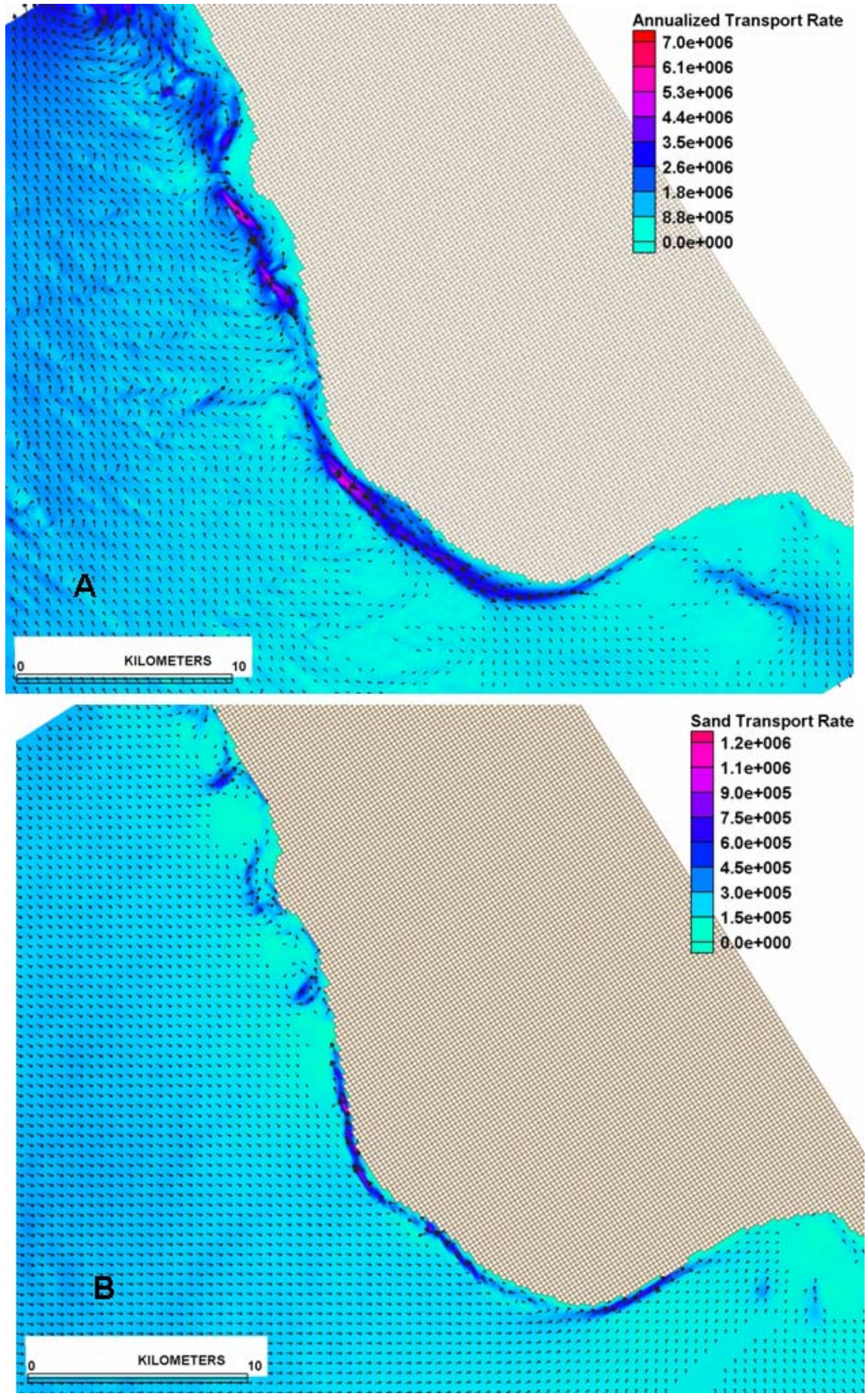


Figure 4-19. Sand transport rates (annualized) for the T1/T2 model during the 1998 winter storm (A) and during Tropical Storm Harvey in September 1999 (B). Higher transport rates in the littoral zone result from wave driven longshore currents.

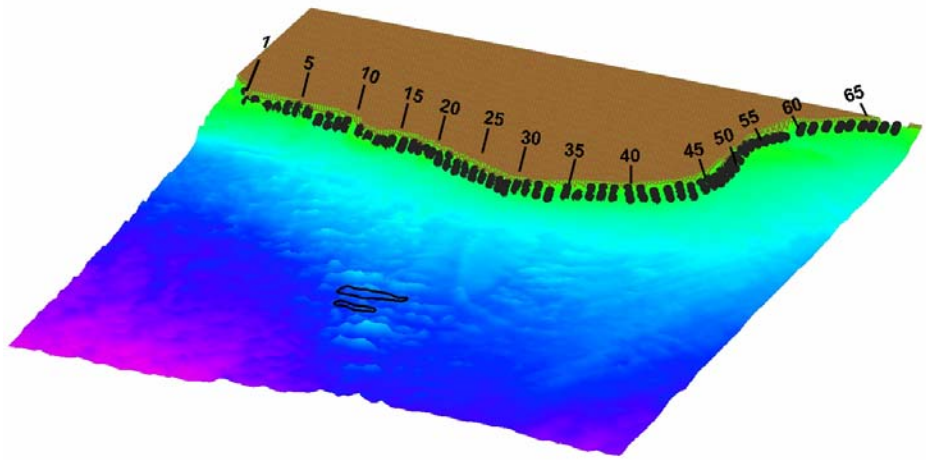


Figure 4-20. Location and identification of numerical observation stations positioned in the littoral zone of the T1/T2 model grid.

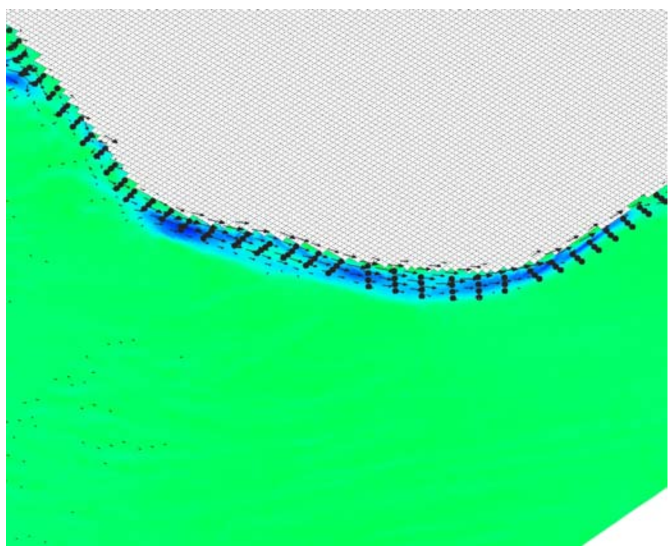


Figure 4-21. Example of T1/T2 model numerical observation stations (Stations 20 – 50) positioned in the littoral zone of Sanibel Island to capture wave generated longshore currents and sand transport.

Figure 4-22 shows the results of longshore sand transport calculations in the littoral zone configured from north to south along the Florida coast. The calculations were summed over the two-year simulation period with net sand transport values presented on an annualized basis. Positive values indicate net sand transport to the north and negative values indicate net sand transport to the south. Figure 4-22 also includes the annualized longshore transport predicted at the shoreline after the 2006 borrow cut in the T1 shoal, Case 2, was positioned in the model topography (see Figure 4-9) along with Case 3 that includes all T1/T2 shoal borrow cuts (see Figure 4-10). As described by Davis et al. (2003), the direction and rates of net longshore sand transport along the west coast of Florida are variable due to coastal morphology and the influence of tidal inlets. However, a comparison of the net shoreline changes between 1976 and 2001

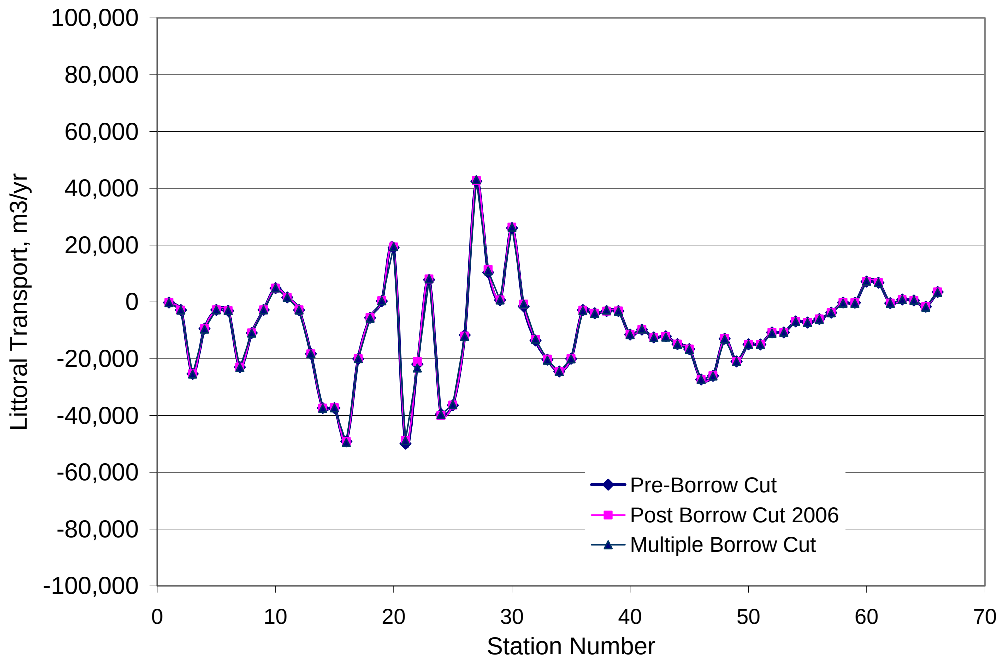


Figure 4-22. Predicted annual longshore sand transport from the T1/T2 model based on a 2-year model simulation. The results for Case 1 (Pre-Borrow Cut), Case 2 (Post Borrow Cut 2006) and Case 3 (Multiple Borrow Cuts) are shown. Positive values indicate net transport to the north and negative values indicate net transport to the south. Locations of the recording stations in the model are shown in Figure 4-20.

compiled by the USGS (2003) with gradients of net longshore transport based on the 2-year model simulation (Figure 4-23) indicates that the model predicted transport is qualitatively consistent with measured shoreline changes.

Generally, large gradients of net transport produced from model simulations were in areas of net shoreline retreat or accretion depending on whether the gradients indicate an increase or decrease in longshore transport. In the zone between 33 and 46 km (Figure 4-23) the predicted gradients are small and correspond to a zone of low shoreline change rates. Between Stations 18 and 26 (Figure 4-23) measured shoreline changes between 1976 and 2001 indicate an area of shoreline accretion although there is considerable variability in the predicted rate and direction of net sand transport. However, the shoreline in this area has been influenced by repeated beach fill projects during the past two decades (CPE, 2003). The strong gradients and variability in littoral transport predicted by the CMS indicate that this area is subject to erosion reflecting the ongoing need for beach nourishment. Overall, the qualitative agreement between trends of shoreline change and predicted sand transport patterns indicate that the model simulations are qualitatively in good agreement with predicted sand transport in the littoral zone.

The magnitude of annualized sand transport rates are similar for the three model test cases that examine the potential influence of borrow cuts at the shoreline (Figure 4-22). The variability in the predicted net direction of littoral transport and rate is consistent with the variability of the net littoral sand budget described by Davis et al. (2003) and reflects the physical conditions of the model area (see Figure 2-31).

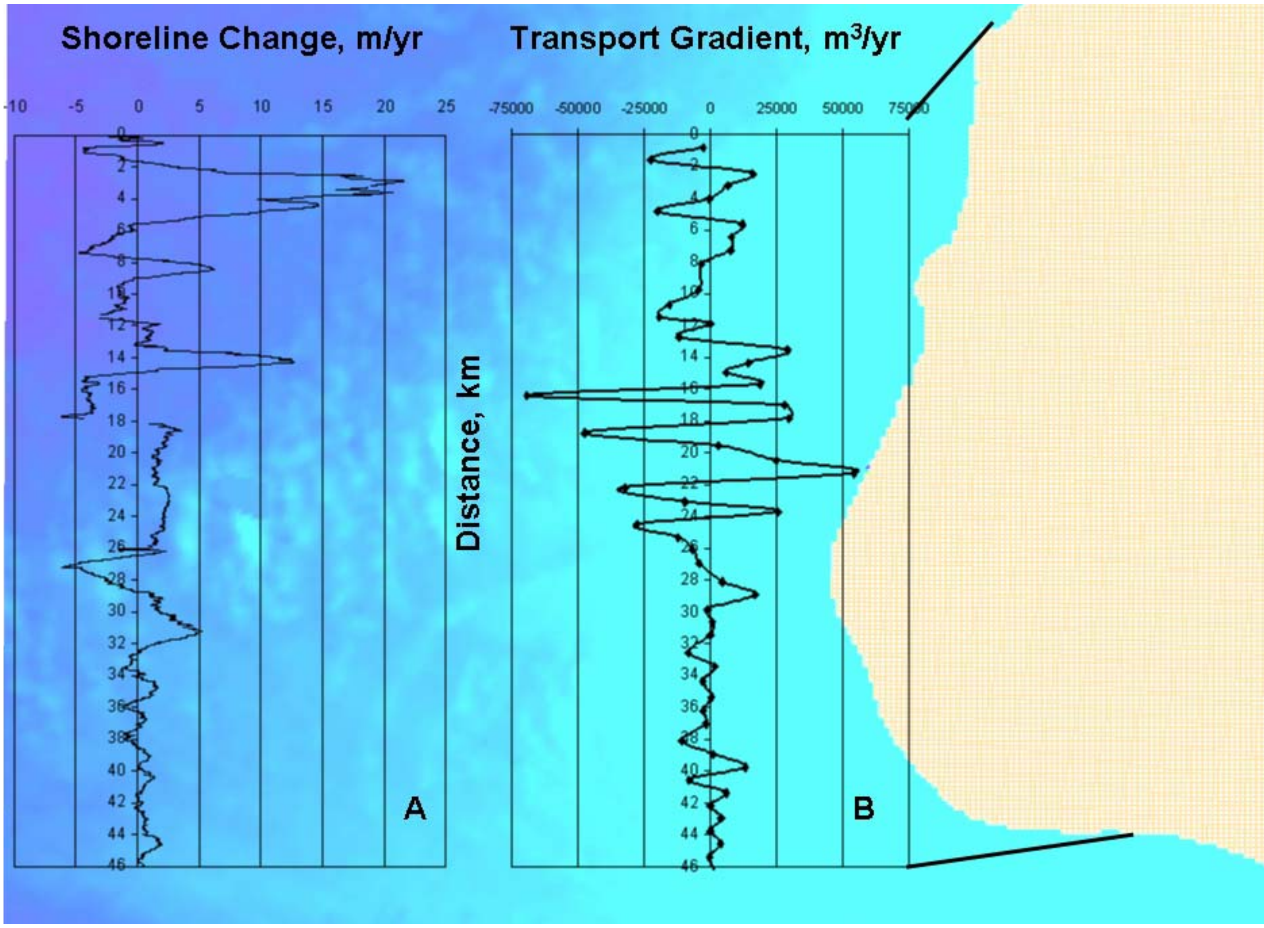


Figure 4-23. Comparison of measured shoreline change rates from the T1/T2 model between 1976 and 2001 (A) and predicted gradients of net longshore sand transport.

The differences in predicted net littoral sand transport among Case 1 (Pre-Borrow Cut), Case 2 (Post Borrow Cut 2006), and Case 3 (Multiple Borrow Cuts) are shown in Figure 4-24. In order to fully consider the importance of the magnitude of the predicted differences among the model test cases, an annualized standard deviation was calculated for each numerical monitoring station for Case 1, the pre-borrow cut condition. The standard deviation represents the variability of the predicted littoral transport at each location over the two-year model run. If the magnitude of the difference between Case 1 and Case 2 or 3 reaches the level of the transport standard deviation at a particular station there may be a potential for detectable influence at that location. As seen in Figure 4-24, differences between Case 1 and Case 2 or 3 are small compared to the annualized standard deviations at the observation stations. However, at Stations 21, 28 and 31 the predicted difference for Case 3 meets the standard deviation envelope, whereas the standard deviation envelope is reached at Stations 21 and 28 for Case 2. At these locations the magnitude of the difference is the same as the variability described by the standard deviation for Case 1 but no larger. This zone between Stations 20 and 32 is located on the onshore projection of the north and south boundaries of the T1/T2 shoal area. Although the T1/T2 shoal is more than 10 miles offshore the apparent "zone of influence" correlates with littoral zone closest to the shoal.

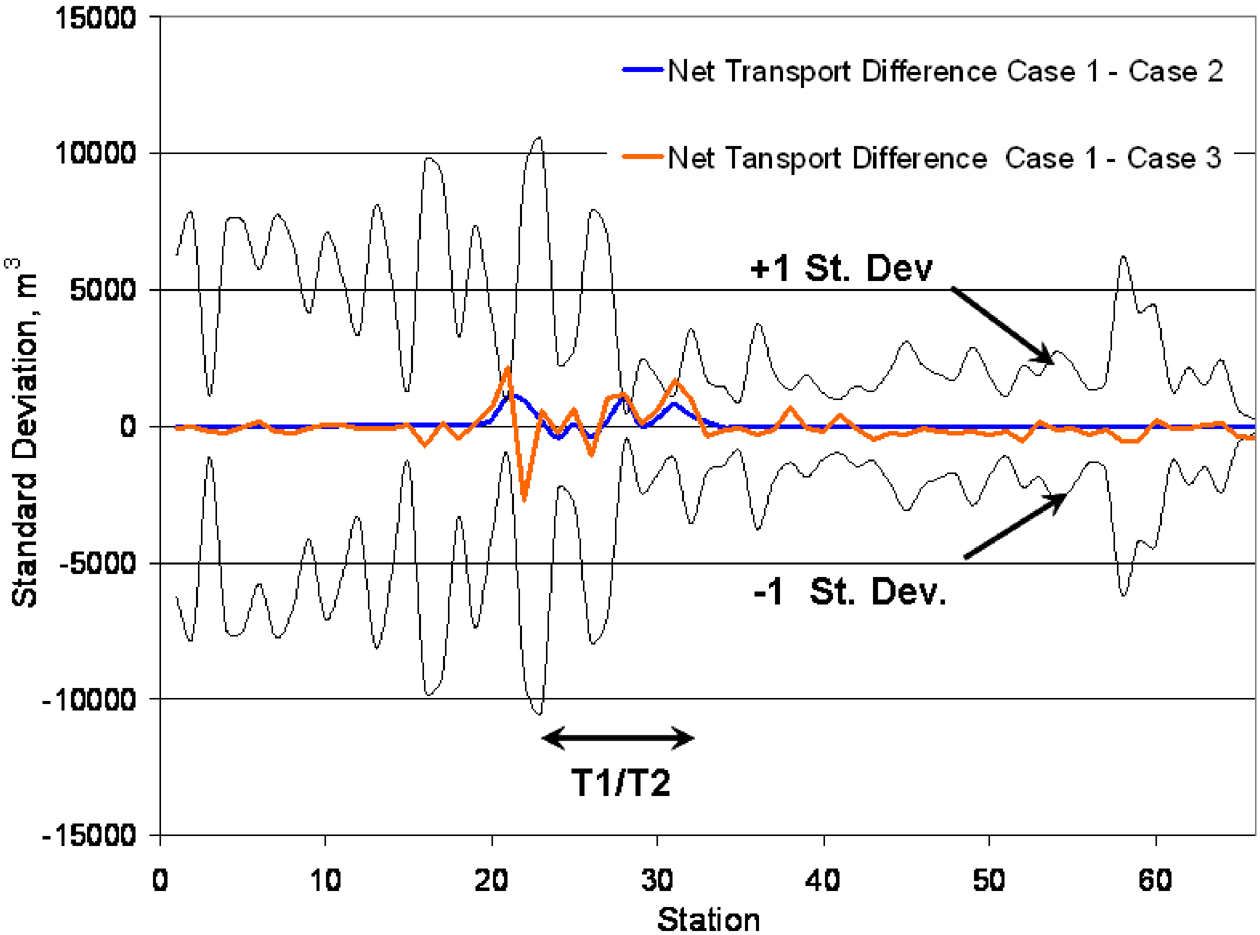


Figure 4-24. Difference in predicted net littoral sand transport based on the T1/T2 model between Model Case 1 (Pre-Borrow Cut), Case 2 (Post Borrow Cut 2006) and Case 3 (Multiple Borrow Cuts). The differences are shown relative to the standard deviation of transport at each monitoring station.

Predicted Topographic Changes

Most of the predicted topographic change over the 1998-1999 period of simulation occurred episodically as a result of specific storms or higher energy wave conditions. Further, the predicted changes in the nearshore topography during the 2-year model simulation were almost identical among the three T1/T2 cases. However, because there is the potential for some influence at the shoreline, the effect of predicted littoral sand transport on predicted shoreline topographic changes was examined. Predicted differences in the topographic evolution along the upper shoreface were small and generally less than 5 cm (about 2 in.) in any model cell in the littoral zone. Figure 4-25 shows the location of three subsections (A, B, and C) of the T1/T2 study area. Predicted topographic changes are shown in more detail for each subsection in Figures 4-26, 4-27, and 4-28. The overall pattern of predicted topographic change is erosion on the upper shoreface just beyond the shoreline and deposition on the lower shoreface at the end of the two-year model simulation. This pattern can be seen in Figures 4-26, 4-27, and 4-28 along with variability due to smoothing of the original bed topography as the model runs continued.

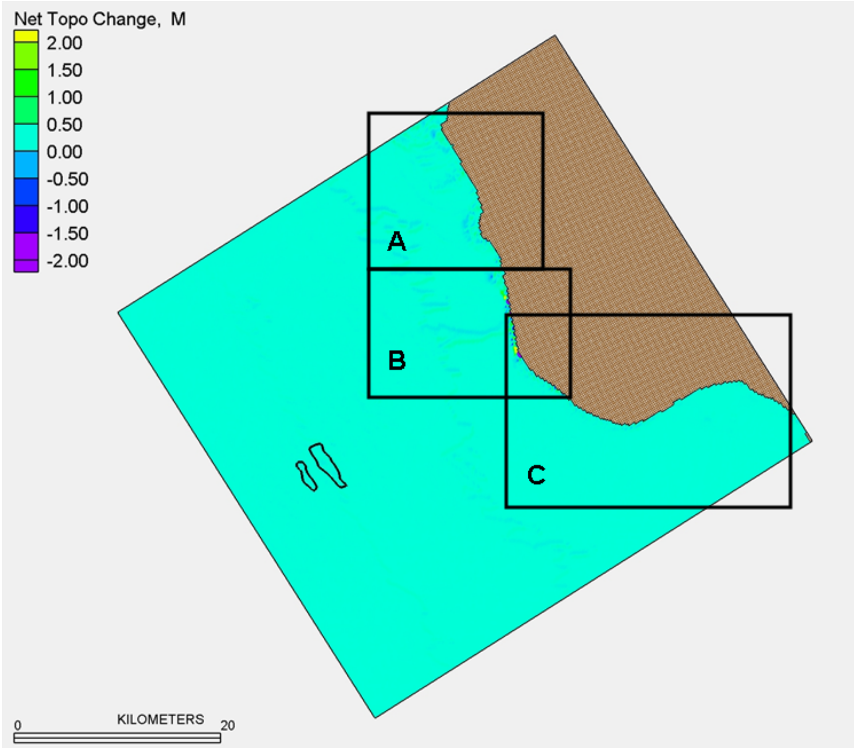


Figure 4-25. Location of three panels shown in Figures 4-26 to 4-28 showing predicted net topographic change after 2-years of simulation based on the T1/T2 model.

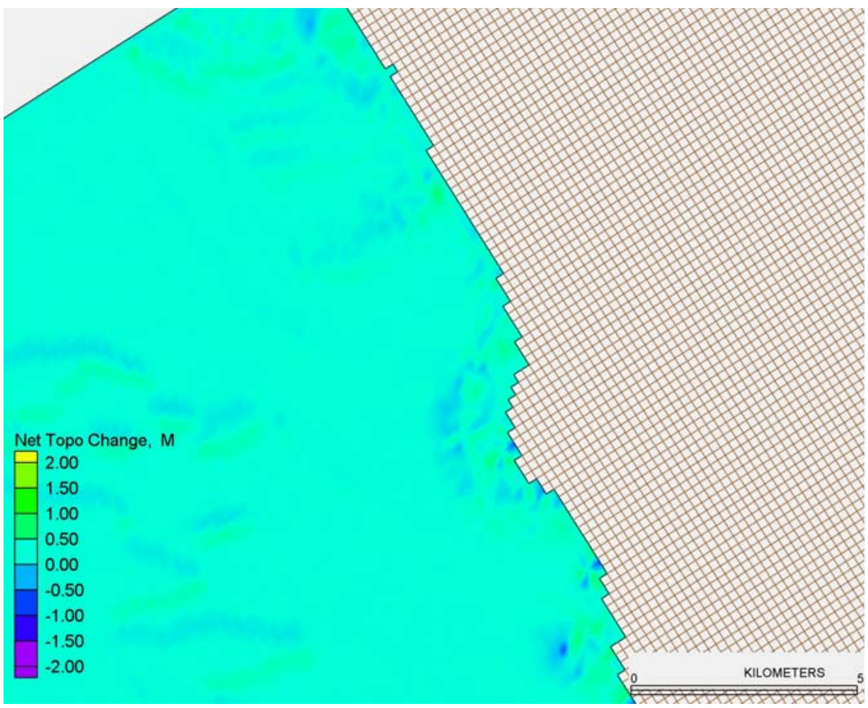


Figure 4-26. Details from Panel A of Figure 4-25 showing the T1/T2 model predicted net change after two years of simulation under Case 2 (single borrow cut).

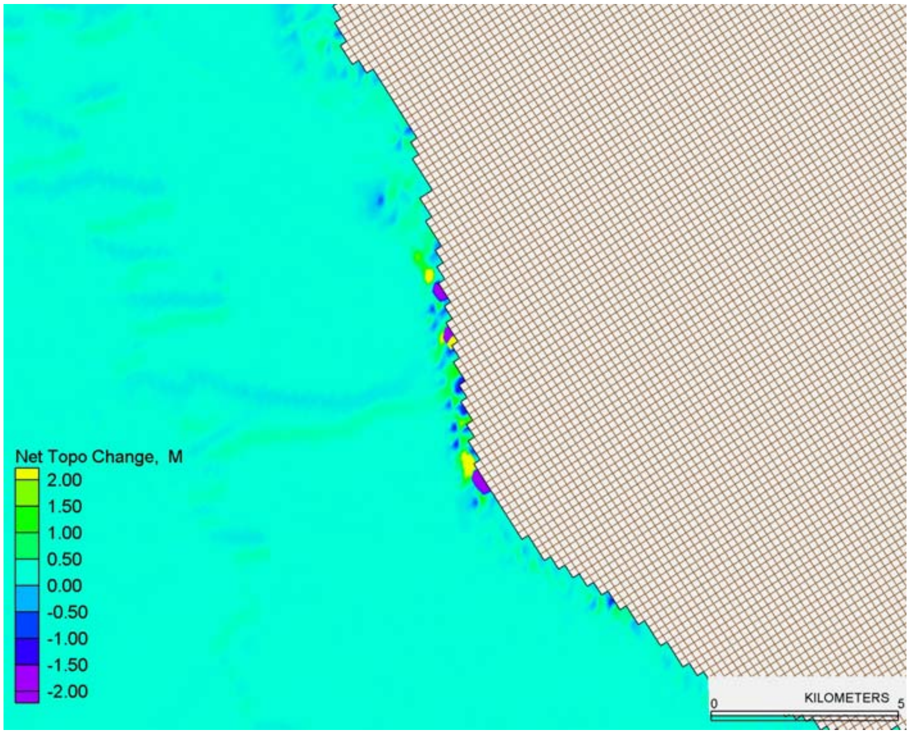


Figure 4-27. Details from Panel B of Figure 4-25 showing the T1/T2 model predicted net change after two years of simulation under Case 1 (No borrow cut).

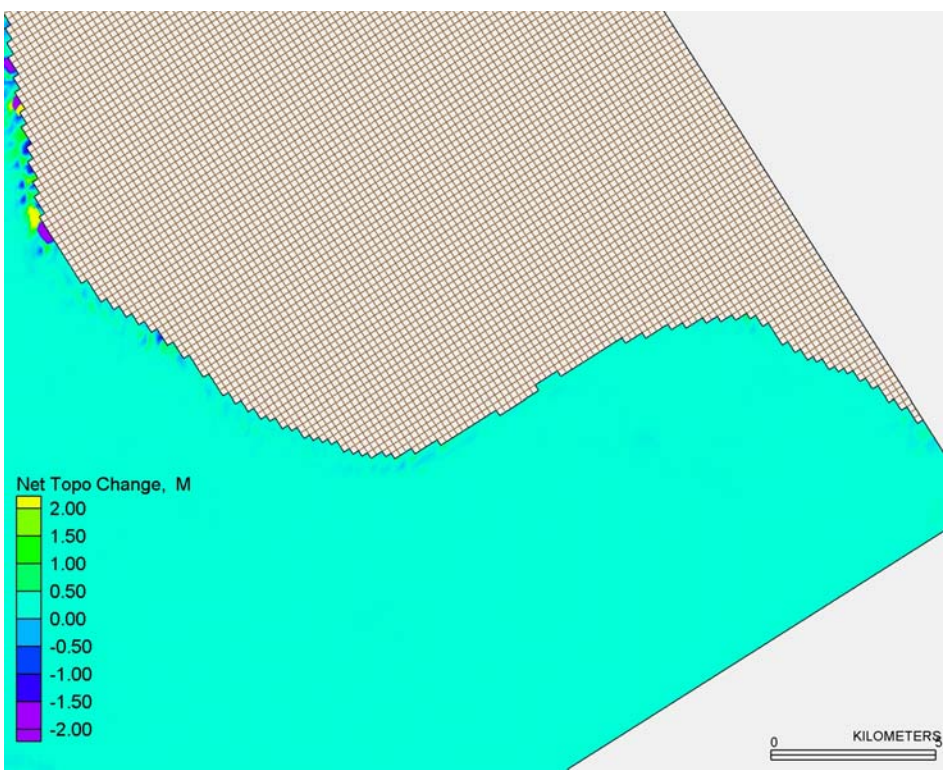


Figure 4-28. Details from Panel C of Figure 4-25 showing the T1/T2 model predicted net change after two years of simulation under Case 3 (Multiple Borrow Cuts).

Topographic differences among the three cases applied to the T1/T2 model were small and difficult to resolve in a regional plot. Therefore, time series of topographic change at selected points in the littoral zone (Figure 4-29) were examined. The time series selected from four stations (Stations 13, 20, 26, and 32) are discussed here since they are located in the area termed the "zone of influence" where differences among predicted sand transport rates can be detected (see Figure 4-21).

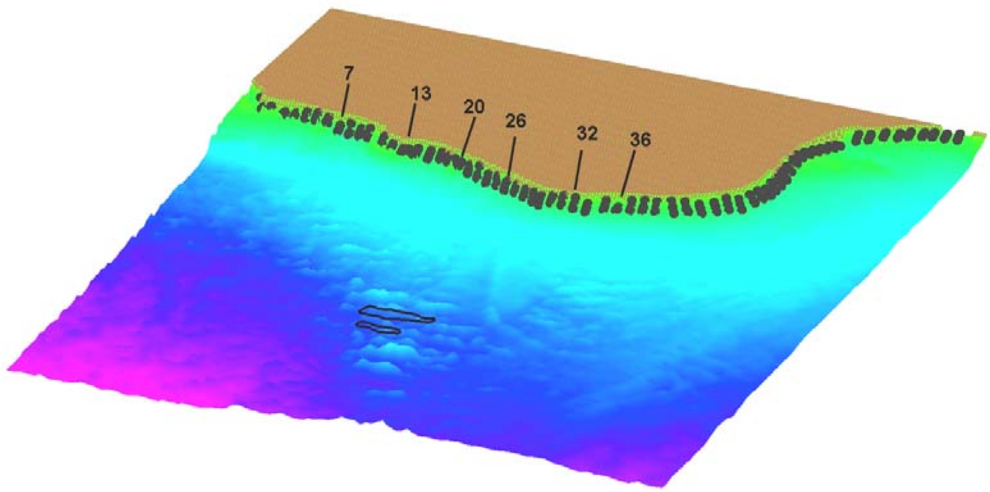


Figure 4-29. Location of monitoring stations in the T1/T2 model grid from which time series of topographic change were extracted for individual cells in a transect across the littoral zone.

Figure 4-30 shows a time series extracted from the upper shoreface at Station 13. The net predicted topographic change is an increase in depth of about 20 cm (about 0.6 ft) or net erosion at this model cell. All the cases have an identical pattern but the trend for Case 3 (multiple borrow cuts) is about 1-3 cm less in magnitude. The predominant result for topographic change was erosion from the upper shoreface and corresponding deposition on the lower shoreface. Figure 4-31 shows the predicted topographic change at monitoring Station 20 for an upper shoreface cell. Erosion of sand in this cell reached about 60 cm or about 1 foot over the two-year simulation. The predictions for Cases 1 and 2 were nearly identical, but the results for the Case 3 (Multiple borrow cuts) varied by about 1-3 cm from the other two cases. In Figure 4-32 sand deposition is predicted on the lower shoreface at Station 26 (see Figure 4-29 for the location). The magnitude of deposition predicted in this cell was about 70 cm or about 2.3 ft. Again, the results for Cases 1 and 2 were almost identical, but for Case 3 the magnitude of the net deposition was about 4 cm greater by the end of the simulation. The upper shoreface cell shown at Station 32 shown in Figure 4-33 was predicted to have about 85 cm (about 2.8 ft) of erosion over the 2-year simulation. The difference between Case 3 and the other two model cases was detectable but very small about 1 - 2 cm. (less than 1 inch).

In other areas of the T1/T2 model grid topographic prediction results in the littoral zone were similar consisting of erosion on the upper shoreface and deposition on the lower shoreface. However, outside of the area termed the "zone of influence" predicted topographic differences among the three cases were near zero.

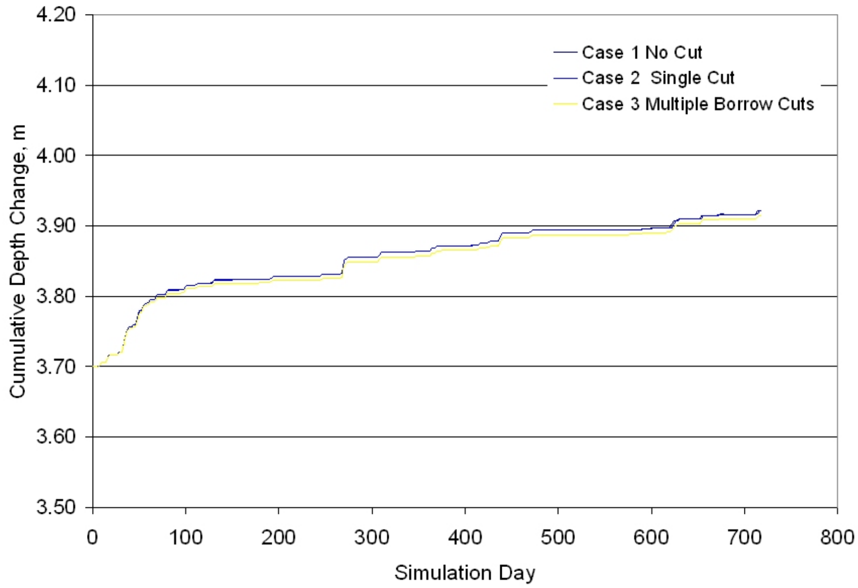


Figure 4-30. Comparison of predicted topographic change on the upper shoreface at Station 13 over the two-year T1/T2 model simulation. Location of station is shown in Figure 4-26.

Figure 4-31. Comparison of predicted topographic change on the upper shoreface at Station 20 over the two-year T1/T2 model simulation. Location of station is shown in Figure 4-26.

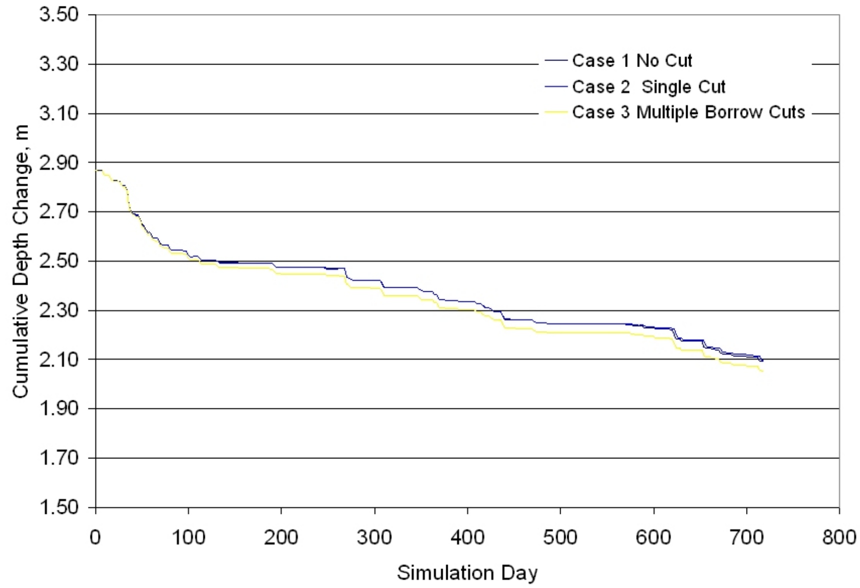


Figure 4-32. Comparison of predicted topographic change on the upper shoreface at Station 26 over the two-year T1/T2 model simulation. Station location of is shown in Figure 4-26.

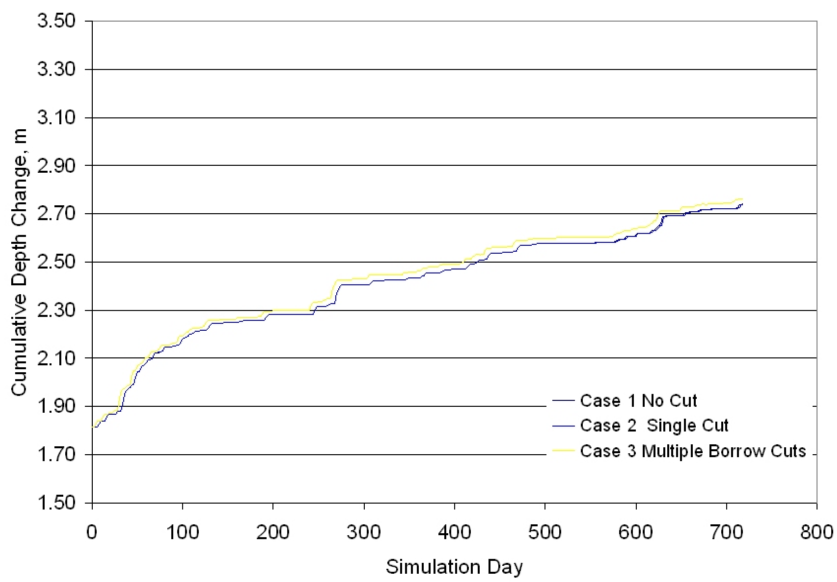


Figure 4-33. Comparison of predicted topographic change on the upper shoreface at Station 32 over the two-year T1/T2 model simulation. Station location of is shown in Figure 4-26.

4.3.9 Model Results: Siesta Shoal

Predicted Changes in Wave Patterns

Figure 4-34 shows the location of the Siesta Shoal approximately 15 miles from the nearest point on the Florida coast within the model domain used to perform the two model test cases listed in Table 4-1. Because Siesta Shoal is a smaller feature compared with the T1/T2 Shoal feature two model cases were run (see Table 4-1). Case 4 consisted of the existing shoal topography, whereas as Case 5 consisted of simulating the removal of approximately 2.3 million cubic meters from the shoal as shown in Figure 4-35. The hypothetical borrow area covering most of the footprint of Siesta Shoal was designed to simulate the culmination of multiple cuts. The average increase in depth over the footprint of Siesta Shoal is about 3 m or about 10 ft.

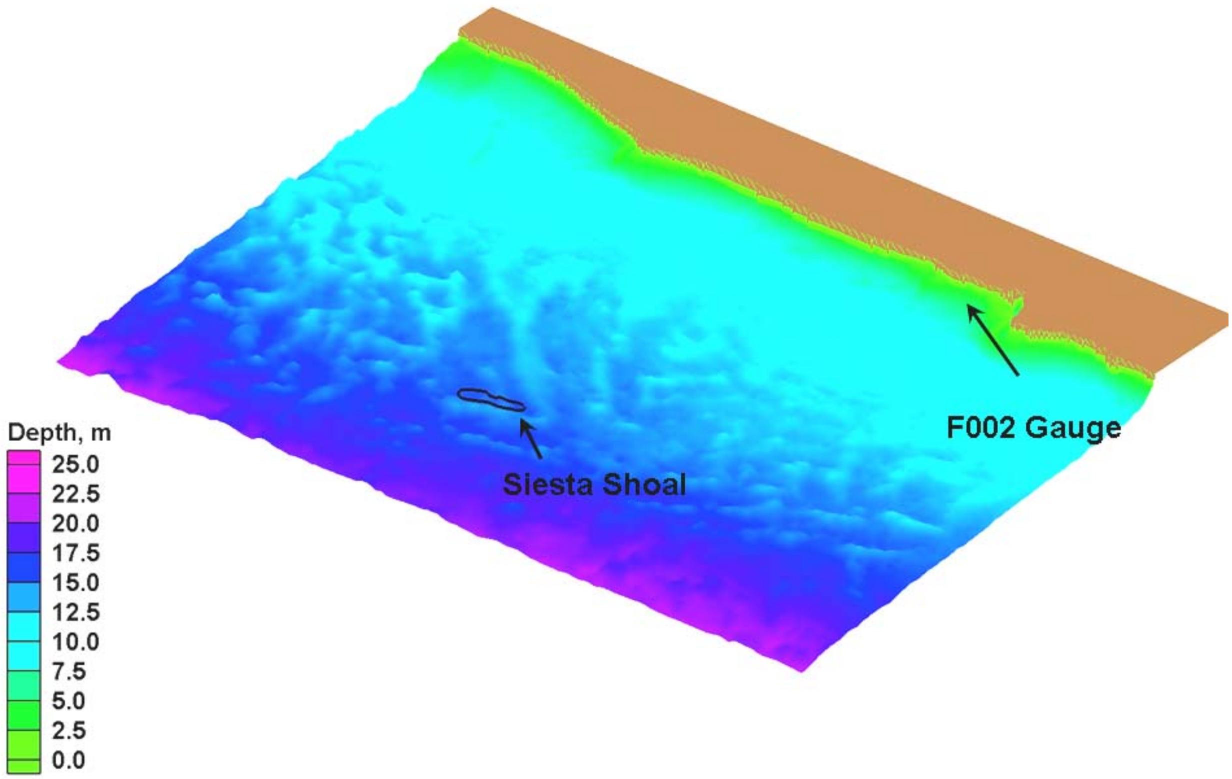


Figure 4-34. Perspective view from the southwest showing the location of Siesta Shoal on the model domain and the location of the USACE F002 direction wave gauge used to verify wave model results. Vertical exaggeration is 200x.

Similar to the analysis performed for the T1/T2 shoal system, the influence of Siesta Shoal on wave fields propagating across the feature could only be detected under the most extreme wave conditions. Because of the smaller size of the Siesta Shoal, its influence of on wave propagation was more restricted than found in the analysis of the T1/T2 Shoal system. Siesta Shoal is approximately 2 miles (3 km) long and about 0.5 miles (0.8 km) wide. At the crest, the elevation of Siesta is about -46 feet MSL (about -14 m). In contrast, the combined width of T1/T2 is about 1.4 miles (2 km) and the length of the larger T1 Shoal is about 3 miles (4 km). Minimum depths along the crest of T1 are about -32 ft (about 10 m).

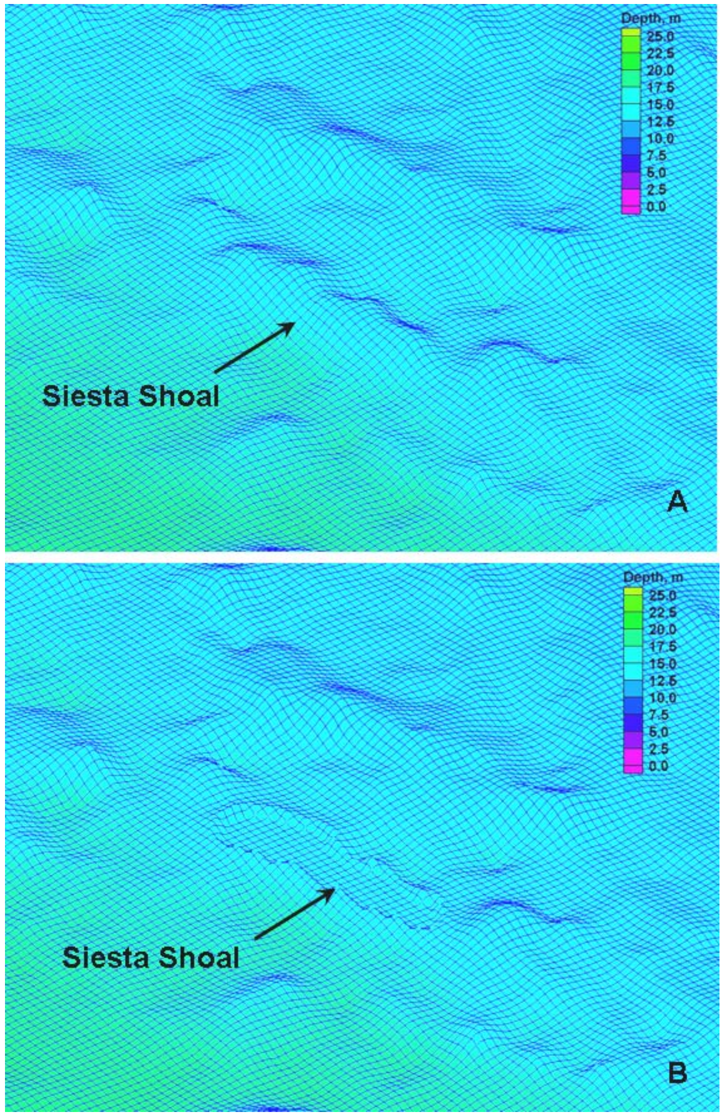


Figure 4-35. Representation of Siesta Shoal topography in the model grid for Case 4 before borrow cuts (Panel A) and for Case 5 after multiple borrow cuts (Panel B).

Refraction effects across Siesta Shoal are undetectable under the most extreme conditions applied during the 1998-99 model period. Figure 4-36 shows the regional predicted wave pattern over the existing shoal topography (Case 4, Table 4-1) near the beginning of the model run during a 1998 winter storm. Using hind cast data, waves offshore of the west Florida coast reached 4 m at a peak period of more than approximately 11s. In this event, waves approach from the west crossing the short axis of Siesta Shoal (Figure 4-36). Figure 4-37 shows the details of wave moving over the shoal. When compared to the same event in the T1/T2 area (see Figure 4-12A), no bending of the wave rays depicting a shift in wave direction was detected.

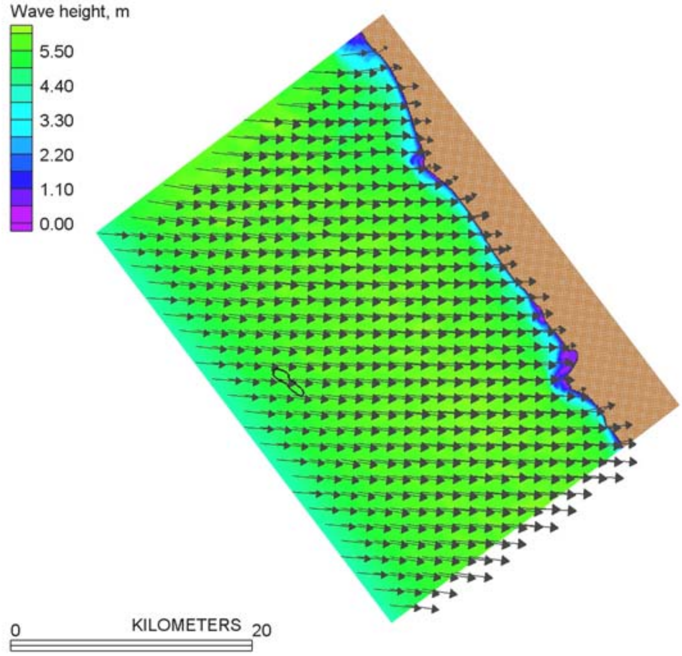


Figure 4-36. Wave pattern over the Siesta Shoal model grid for Case 4 during a winter storm producing high wave energy conditions in February of 1998. Significant wave heights are 4m and peak wave period 11s. Reduction of wave heights can be seen (in purple) near the shoreline as wave breaking occurs in shallow water.

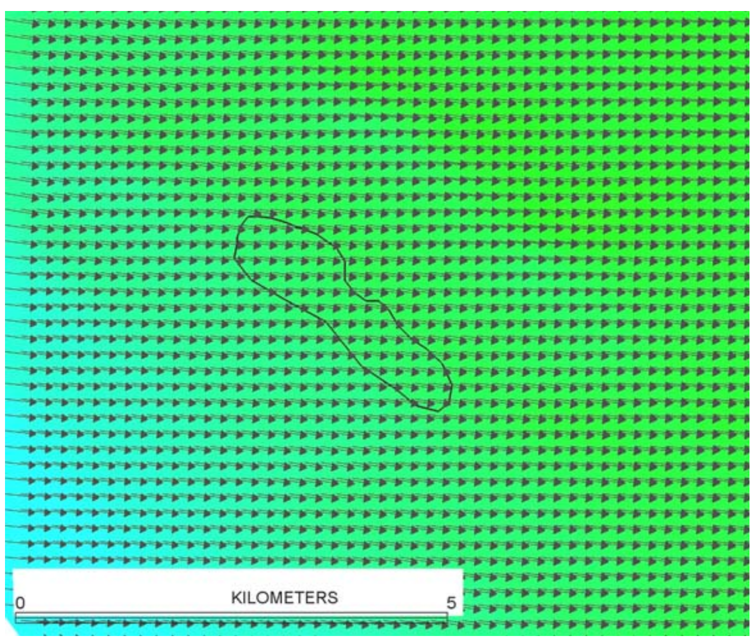


Figure 4-37. Details of predicted wave movement over Siesta Shoal during the 1998 winter storm. Maximum wave heights over the shoal are 4 m, whereas the wave period is 11s. Refraction or bending of wave rays tracing the movement of wave energy is not apparent.

Figure 4-38 shows predicted regional wave patterns during Tropical Storm Harvey in September of 1999. The overall pattern is similar to that predicted over the T1/T1 model grid (see Figure 4-11) in which wave energy propagating to the north is eventually refracted to the east while crossing the decreasing depths of the inner continental shelf of west Florida. However, locally over Siesta Shoal, refraction of wave energy is not detectable in the model prediction as it was over the larger T/1/T2 Shoal system (Figure 4-39). A comparison between Figure 4-39 and Figure 4-12, depicting conditions during the same storm, shows that the larger T1/T2 Shoal had detectable influence on the direction of wave energy movement.

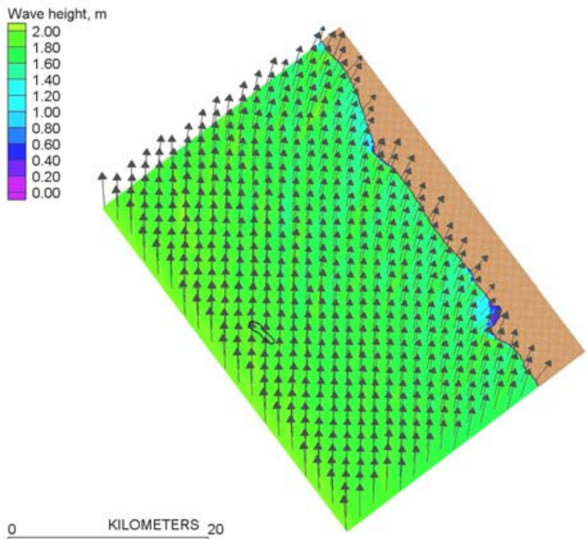


Figure 4-38. Predicted regional wave patterns of the Siesta Shoal associated with Tropical Storm Harvey in September 1999. Maximum predicted wave height over the shoal is approximately 2m at a wave period of 10s.

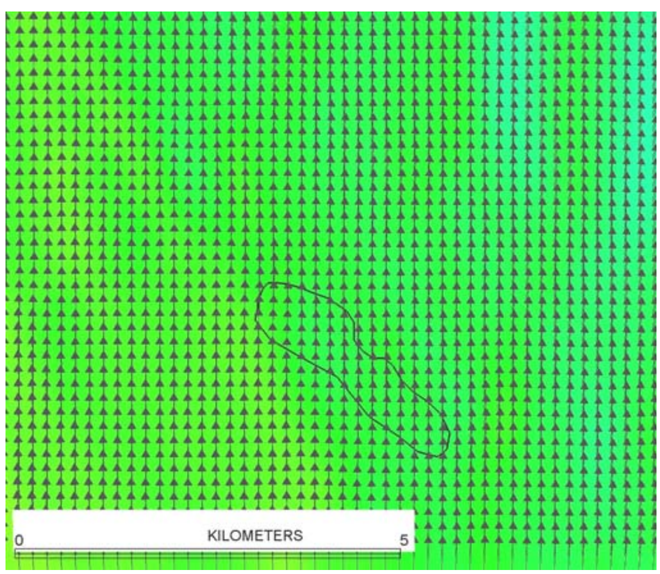


Figure 4-39. Details of predicted wave energy propagation over Siesta Shoal during Tropical Storm Harvey. Refer to Figure 4-12 for a comparison to the T1/T2 Shoal feature. Model topography is for the existing morphologic situation of Siesta Shoal (Case 5, Table 4-1).

A survey of the results of wave model predictions over Siesta Shoal for the existing topography (Case 4 , Table 4-1) and after placement of the hypothetical large borrow cut in Siesta Shoal (Case 5, Table 4-1) yielded only one event which predicted significant wave height differences. Waves moving to the north at a period of 10s during tropical Storm Harvey in 1999 were predicted to have a different wave height pattern after cumulative borrow cuts (Figure 4-40). Although, the influence of borrow cuts on the direction of wave energy movement was not predicted to occur, the influence of borrow cuts on wave height included an increase of up to 0.15 m (about 0.95 ft) directly to the north of Siesta Shoal along with zone of minor reductions in wave height to the north and east of the shoal (Figure 4-40). However, examination of the regional wave field showed that differences in wave height between the Case 4 and Case 5 were reduced to zero in the nearshore and littoral zone. It is likely that small changes in the wave field over Siesta Shoal located more than 15 miles offshore were overwhelmed by the influence of shoaling transformation over the shallow water east of the shoal and irregular bottom topography as wave energy propagated to the shoreline.

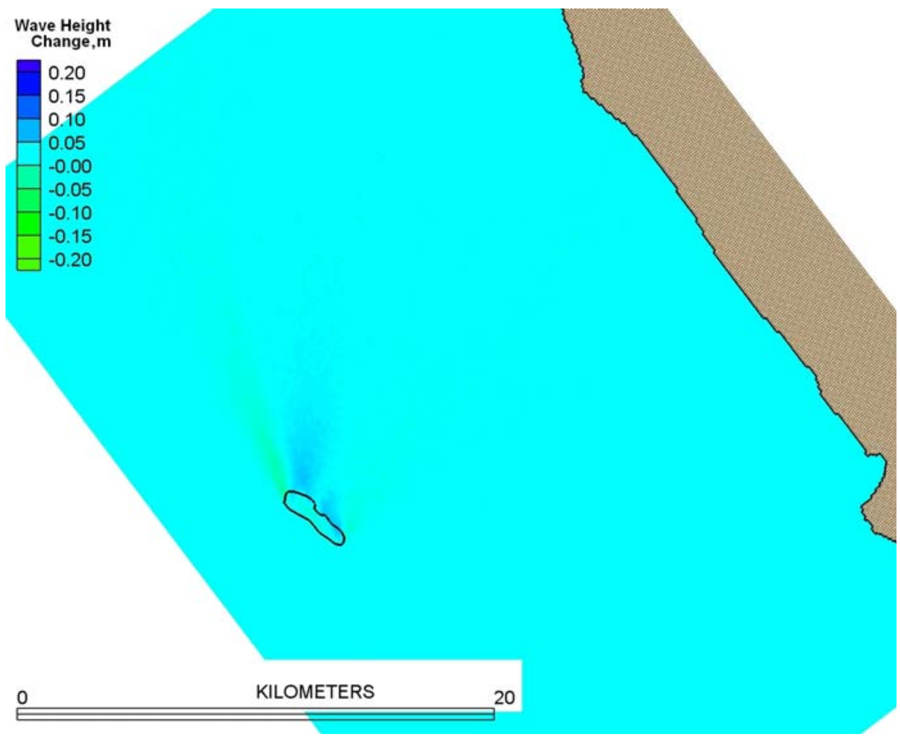


Figure 4-40. Predicted change in wave height patterns after the Siesta Shoal topography was modified by a large borrow cut (see Figure 4-32). Wave conditions in the simulations are associated with the passage of Tropical Storm Harvey in September of 1999.

Predicted Sand Transport and Topographic Change

The results of the model analysis of Cases 4 and 5 (Table 4-1) applied to the Siesta Shoal region indicate that little or no influence on the wave field will occur in the nearshore and littoral zone landward of the shoal even if most of the shoal is removed for beach fill (Case 5). However, predictions of nearshore circulation, sand transport, and topographic change were carefully examined to confirm this conclusion. Similar to model test Cases 1, 2, and 3 applied in the T1/T2 region of the West Florida inner continental shelf, predicted circulation and associated sand transport rates for the Siesta Shoal Cases 4 and 5 were weak during most of the 2-year simulation. Predictions of strong nearshore circulation and transport occurred only during storms and periods of higher wave energy propagating into the area from the Gulf. Figure 4-41 illustrates this for the winter storm of February 1998 and Tropical Storm Harvey in September of 1999. Peak wave conditions for these events are shown in Figures 4-38 and 4-39.

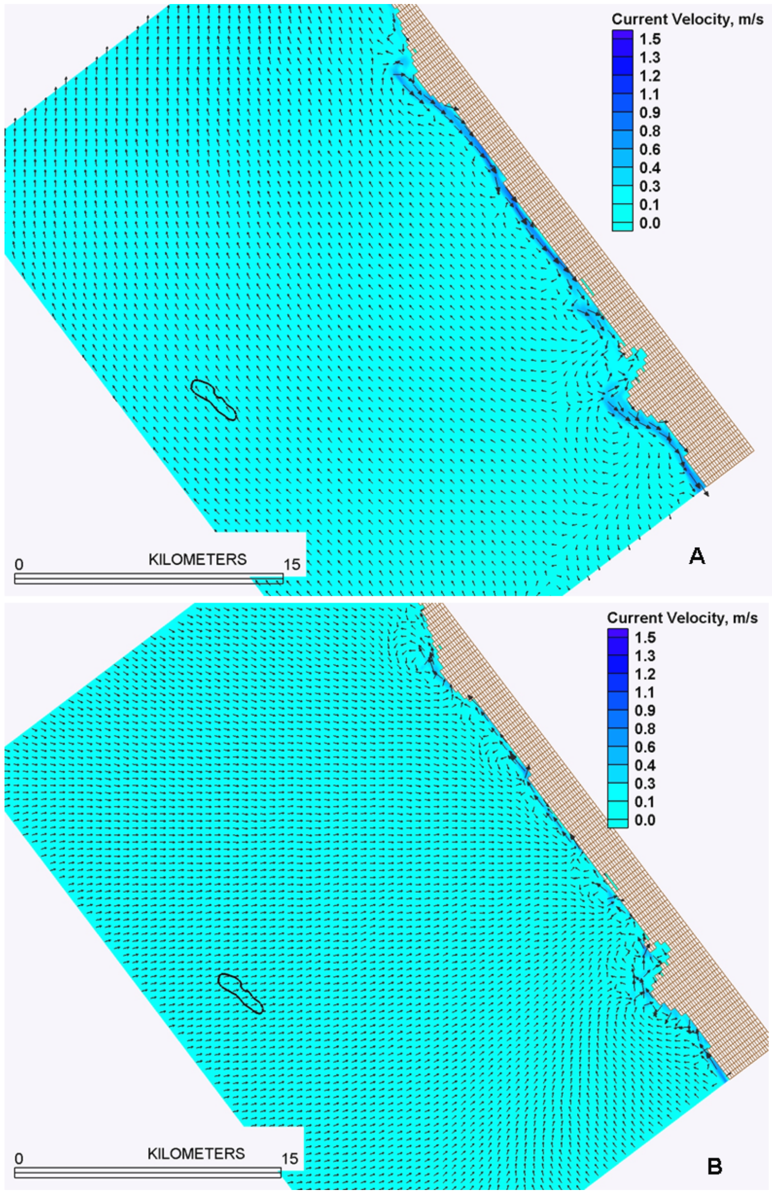


Figure 4-41. Predicted velocity field generated from the Siesta Shoal model during the February 1998 winter storm (A) and Tropical Storm Harvey in September 1999 (B). Stronger currents in the nearshore zone were produced by breaking waves.

Figure 4-42 shows the predicted sand transport rate associated with the current velocity predictions shown in Figure 4-41. The instantaneous transport rates are annualized for ease of comparison. In the case of the 1998 winter event, the storm-produced littoral transport rates if extrapolated to an annual basis would result in a total transport of between 500,000 and 1.5 million cubic yards. The smaller, lower energy waves associated with the tropical storm, if annualized, would produce a total transport between 300,000 and 1 million cubic yards in the littoral zone.

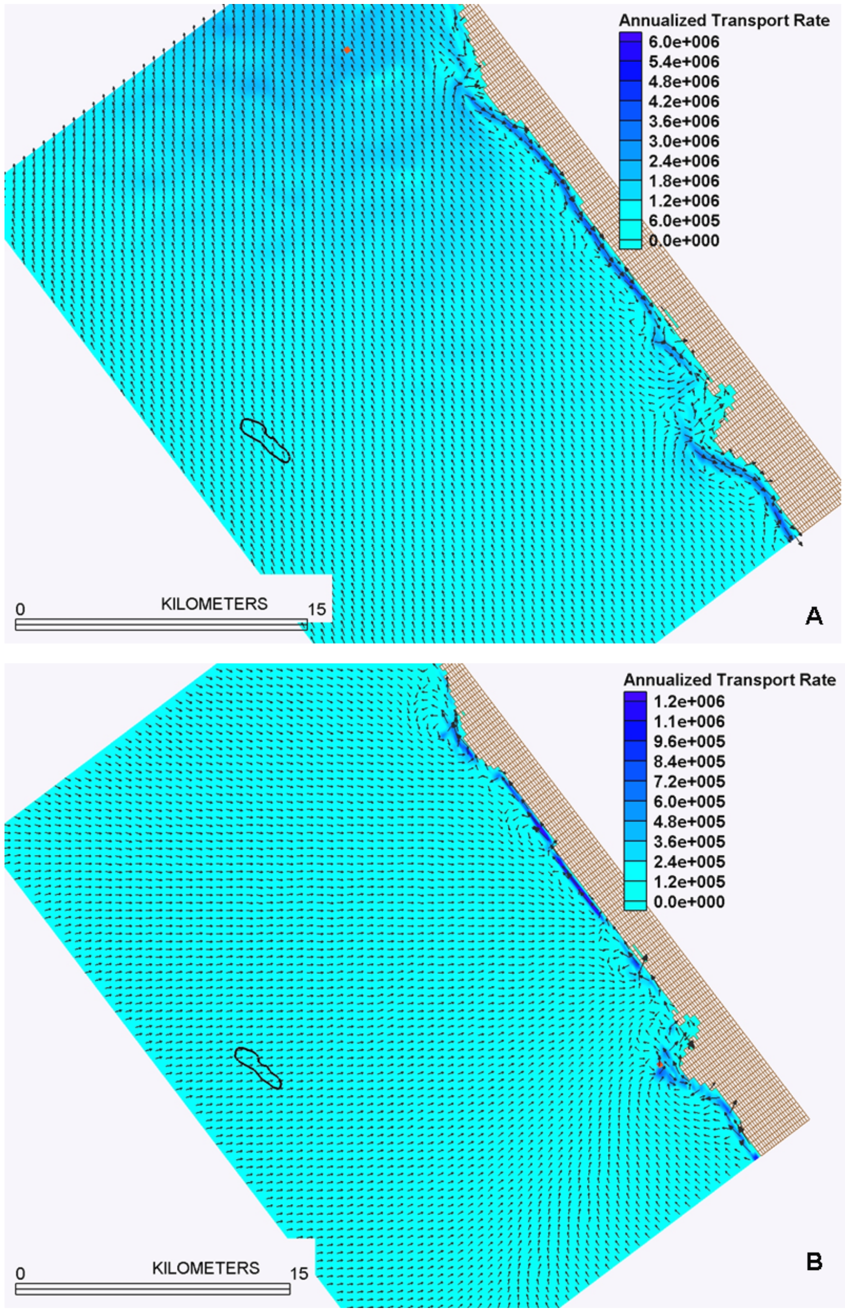


Figure 4-42. Annualized predicted sand transport rates generated from the Siesta Shoal model during the February 1998 winter storm (A) and during Tropical Storm Harvey in September 1999 (B). Higher transport in the littoral zone results from wave-driven longshore currents. Units are in cubic yards per year.

Numerical observation stations placed in the littoral zone of the Siesta Shoal regional model are shown in Figure 4-43. Model predictions of sand transport and topographic change were recorded at these stations for Siesta Shoal model Cases 4 and 5 (Table 4-1). Figure 4-44 shows the results of sand transport calculations in the littoral zone configured in order from north to south along the shoreline. The calculations were summed over the two-year simulation period and then presented on an annualized basis. Positive values indicate net sand transport to the north and negative transport values indicate net annual

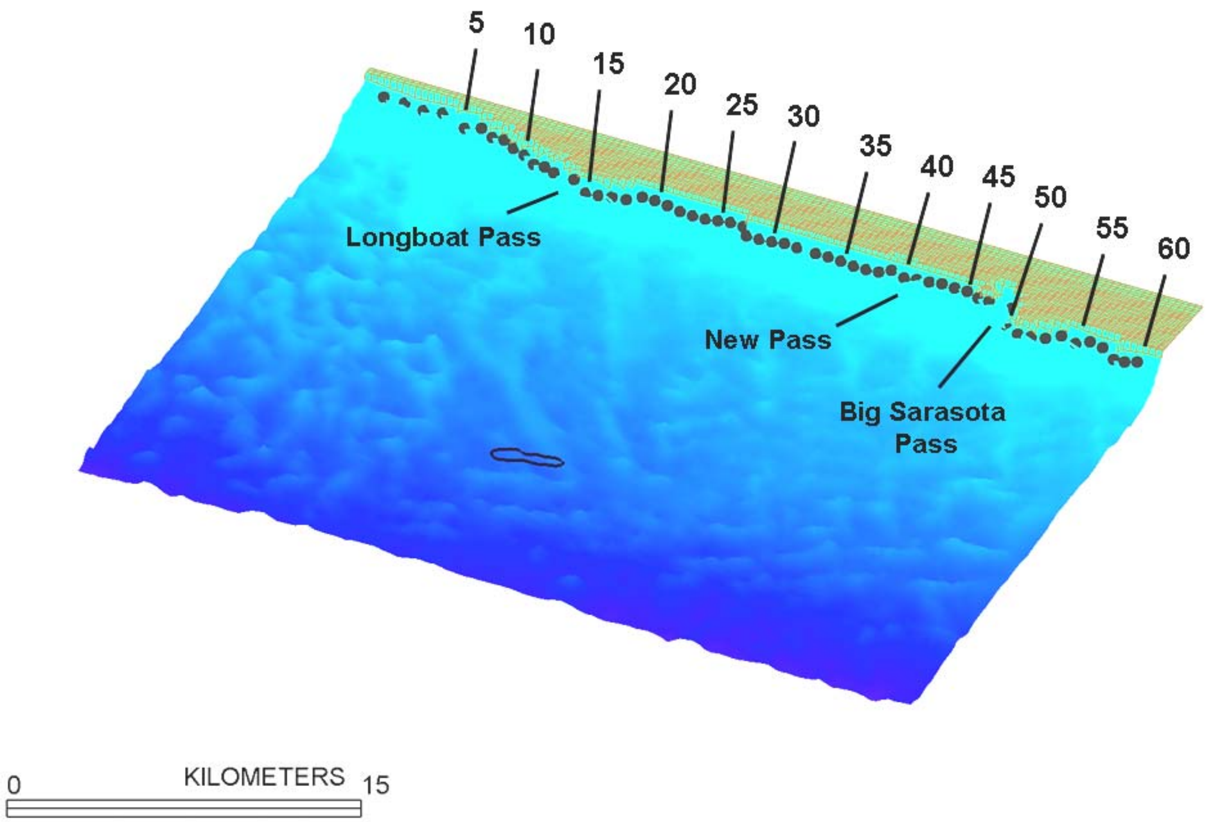


Figure 4-43. Location and identification of numerical observations stations positioned in the littoral zone of the Siesta Shoal model grid. The locations of tidal inlets within the model domain are also shown.

transport to the south. Figure 4-44 also includes the results of both Siesta Shoal model test cases (Table 4-1) including the large borrow cut of Case 5 depicted in Figure 4-35. The net difference in predicted littoral transport between Cases 4 and 5 for Siesta Shoal are minimal and not resolvable in Figure 4-44. Thus, Figure 4-45 plots the net difference in predicted sand transport and makes a comparison with the standard deviation of predicted transport for each numerical monitoring station for the pre-borrow cut condition. The difference between the Siesta Shoal model test cases is generally less than 100 cubic meters on an annual basis and is well below the variability in transport rates that were predicted to occur at the observation stations.

Figure 4-46 compares the predicted longshore gradients of sand transport on an annualized basis with the shoreline changes within the Siesta Shoal model domain between 1976 and 2001. The shoreline changes were compiled by the U.S. Geological Survey (2003). Although there are no regional measurements of the littoral sand budget available the comparison with observed shoreline changes shows that the predicted littoral sand transport and the derivative littoral transport gradient are realistic in pattern. Marked shifts in shoreline change rate and littoral transport gradient are apparent near the ebb shoals of the three tidal inlets within the model area (Figure 4-46). At the north end of the model a high erosion rate and a sharp littoral transport gradient correspond to the reorientation of a shoreface connected shoal off Anna Maria Island just south of Passage Key Inlet between 1976 and 2001.

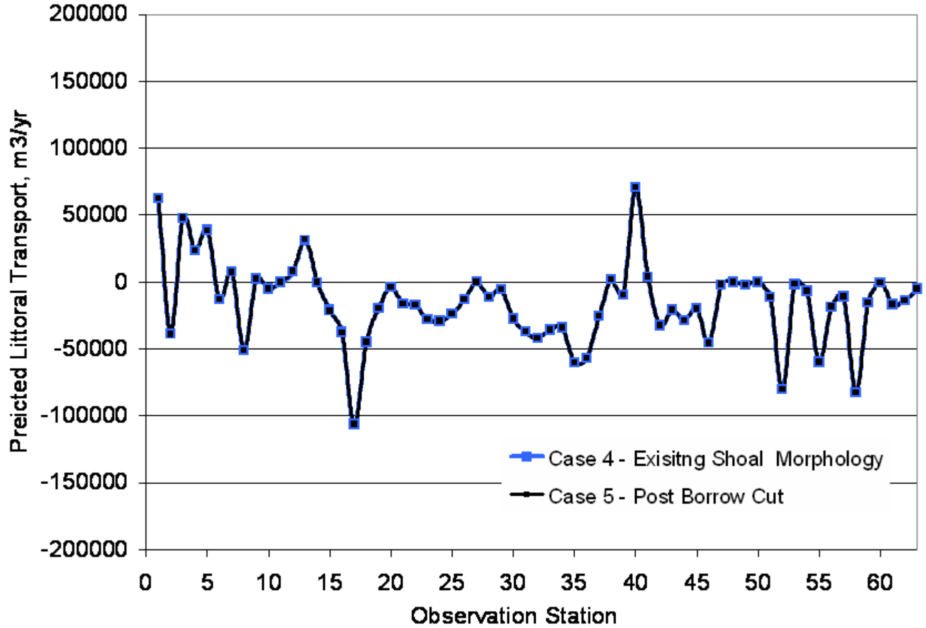


Figure 4-44. Predicted annual littoral sand transport from the Siesta Shoal model based on a 2-year model simulation. The results for Cases 4 and 5 listed in Table 4-1 are shown. Positive values indicate net transport to the north and negative values indicate net transport to the south. Locations of the recording stations in the model are shown in Figure 4-43.

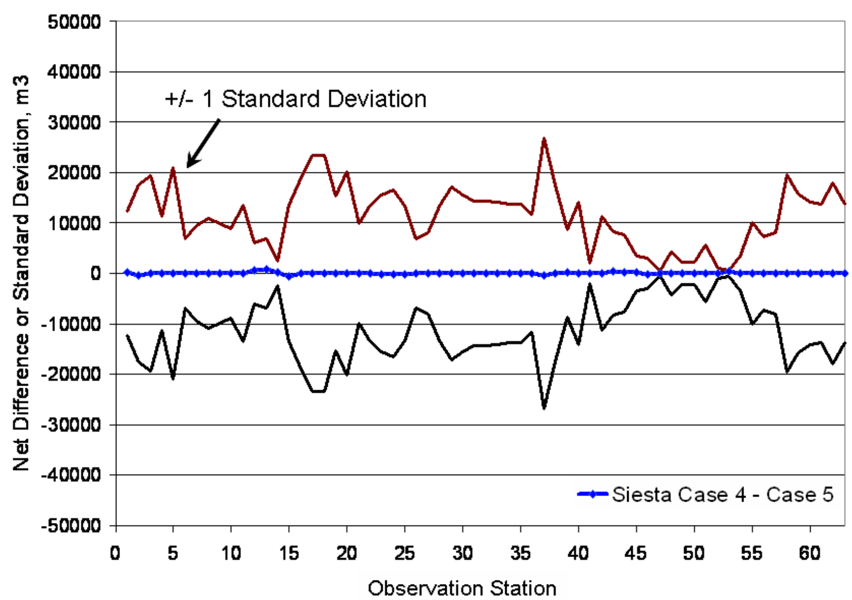


Figure 4-45. Difference in predicted net littoral sand transport based on the Siesta Shoal model between Model Case 4 (no borrow cut), and Case 5 (large borrow cut). The differences are shown relative to the standard deviation of predicted transport at each numerical observation station. The pre-and post- borrow cut morphology is shown in Figure 4-35.

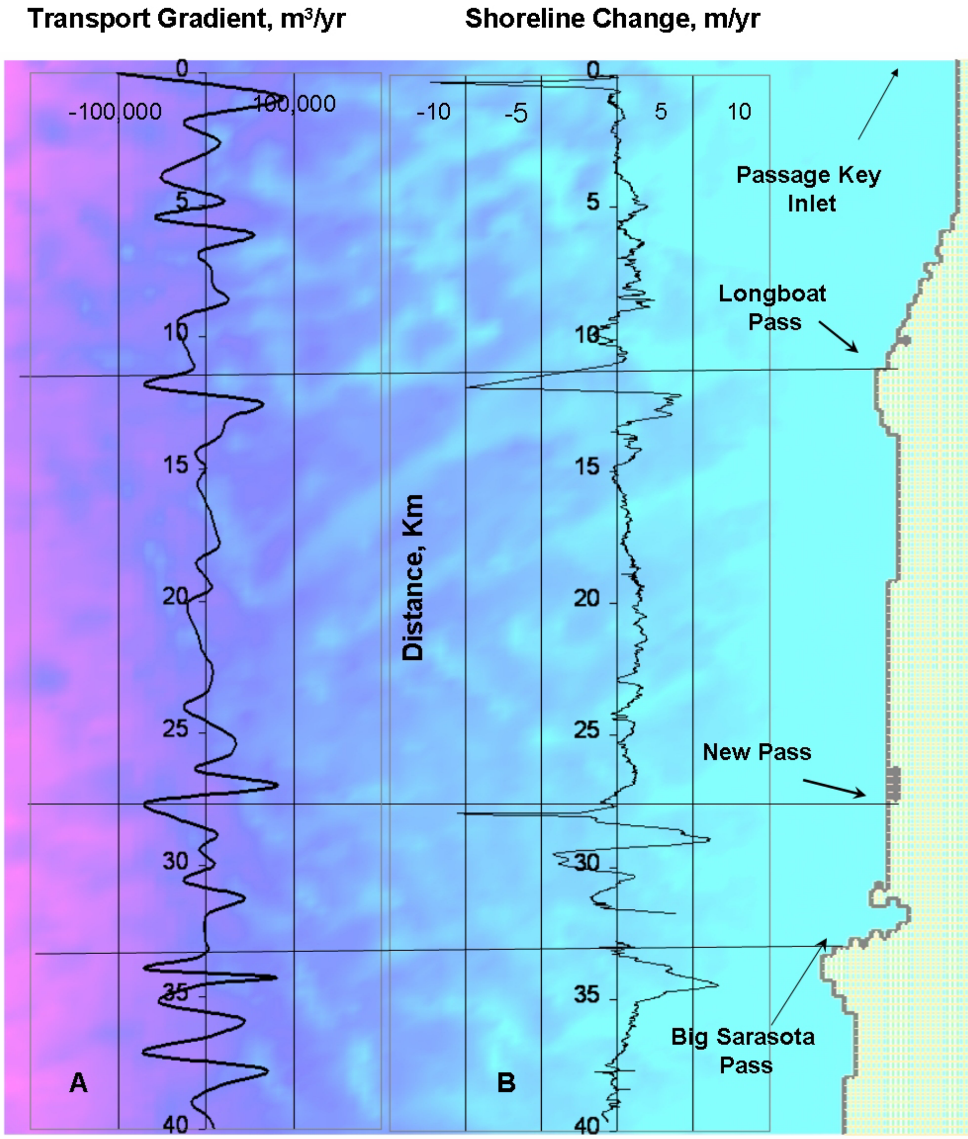


Figure 4-46. Comparison of Siesta Shoal model predicted gradients of littoral sand transport (A) and measured shoreline change rates between 1976 and 2001 (B) compiled by the USGS.

Shoreline segments having low transport gradients generally have positive shoreline change rates. This is particularly true between Longboat Pass and New Pass (Figure 4-46). However, positive shoreline changes are likely to multiple beach fill projects completed on Longboat Key in the 1990s totaling more that 4 million cubic yards of sand. Likewise positive shoreline changes north of Longboat Pass along Anna Maria Island are related to beach fill project in the 1990s.

Figure 4-47 shows the location of two subsections of the Siesta Shoal model area in which predicted topographic changes are shown in more detail in Figures 4-48 and 4-49. The overall pattern of predicted net topographic change is similar to that found in the T1/T2 model results. Some erosion was predicted to occur on the upper shoreface just beyond the shoreline and deposition on the lower shoreface by the end of the two-year model simulation. This pattern can be seen in Figures 4-48 along with spatial variability over ebb shoal features associated with the three tidal inlets in the area.

Figure 4-47. Location of two panels shown in Figure 4-48 (Panels A and B) providing the details of net topographic change after 2-years of simulation under Case 5 for Siesta Shoal (large borrow cut).

Examination of time series of topographic change recorded at the numerical observation stations in the littoral zone (See Figure 4-43 for station locations) showed that virtually no difference could be detected between the model simulation results for Siesta Case 4 that included the existing morphology and Case 5 that included the cut covering most of the shoal foot print (see Figure 4-35). For example, Figure 4-49 plots the predicted topographic evolution at observation stations 20, 30, and 45 during the two-year simulation. The topographic results at these stations and all other observation stations (Figure 4-43) within the Siesta Shoal model domain were virtually identical for both model test cases.

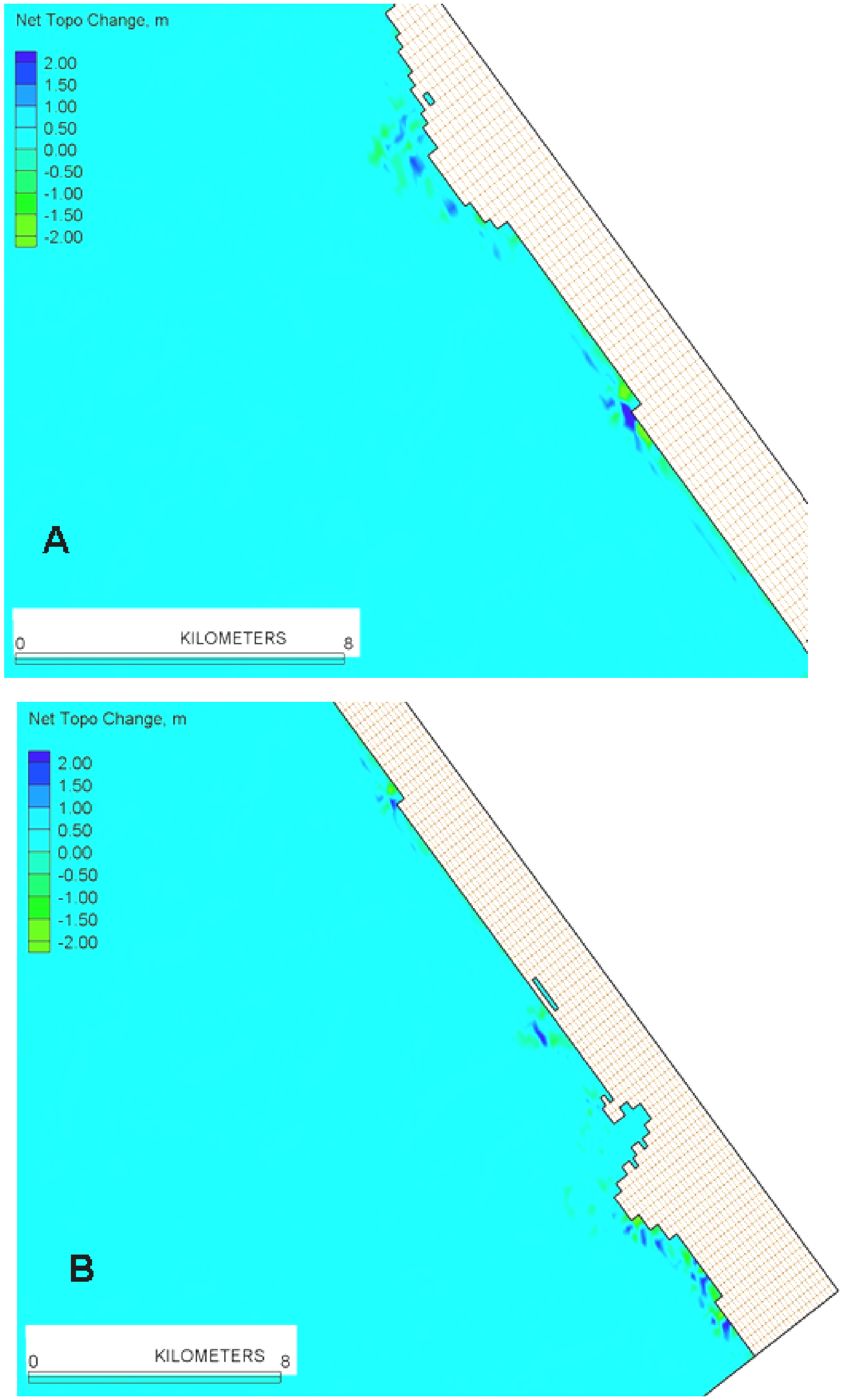


Figure 4-48. Details from Panels A and B in Figure 4-47 showing the predicted net change after two years of model simulation under Siesta Shoal Case 5.

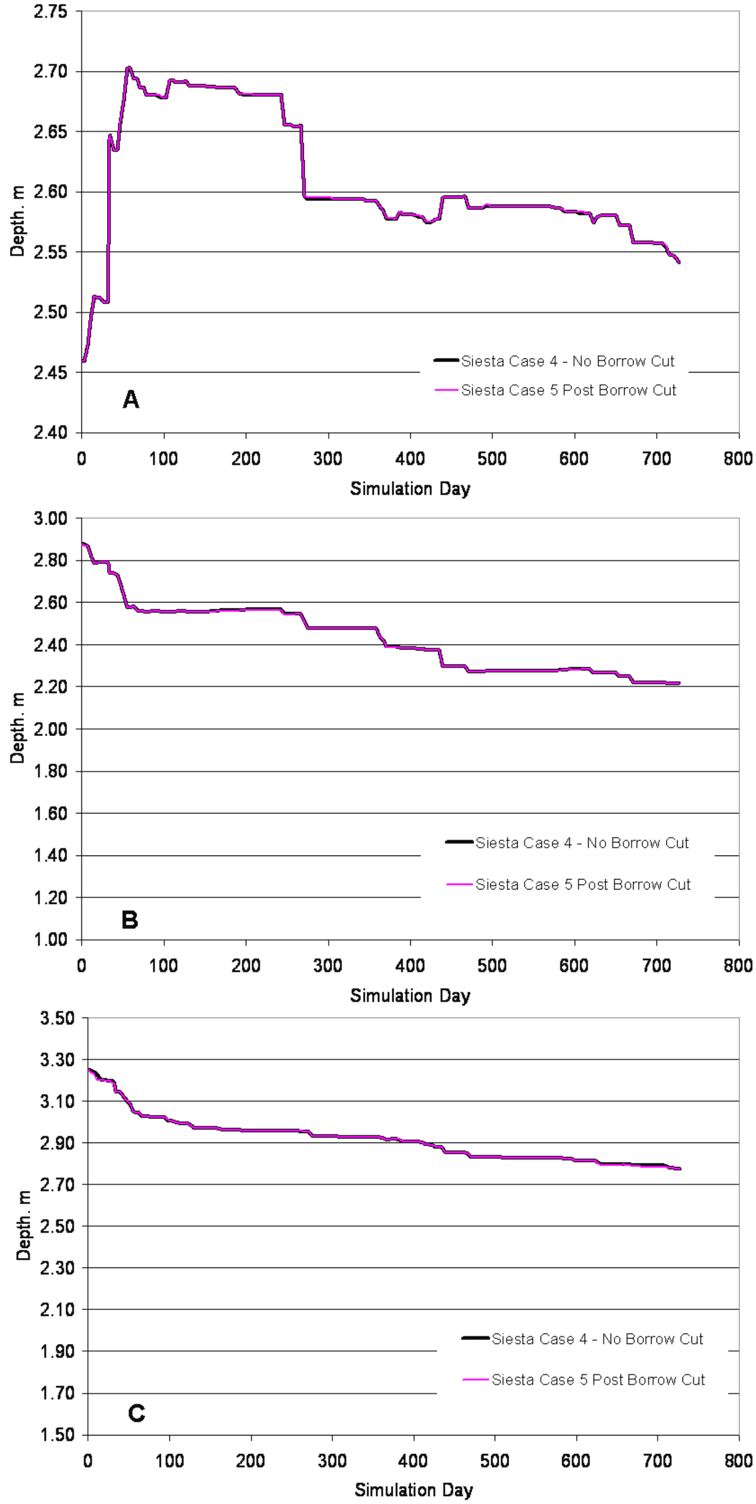


Figure 4-49. Comparison of predicted topographic evolution over the two-year model simulation on the upper shoreface at Stations 20, 30, and 45. Location of the observation stations is shown in Figure 4-43.

4.4 Short-Term and Long-Term Impacts from Dredging to Biological Resources

For this study, the benthic assemblages, fish, sea turtles, sea birds, and marine mammals within the study areas were characterized using the results from the 2005 and 2006 field surveys as well as data provided in existing studies. Dredging offshore borrow areas for beach material can result in negative impacts to the biological communities, especially the resident benthic infauna which have limited mobility. Impacts to the benthos may in turn affect commercially and ecologically important finfish that utilize the benthos as a food resource. Potential impacts to sea turtles, sea birds, and marine mammals are expected to be limited to the active dredging phase of the project with no impacts anticipated after dredging operations and placement of sand on the beach have been completed.

The potential sand resource areas for this study are topographic high features relative to the surrounding seafloor (approximately 2 to 6 m higher than adjacent areas, Section 1.2) with the T1 and T2 areas presenting the highest relief. Previous studies have reported that offshore shoal and ridge features may provide distinctive habitats on an otherwise featureless continental shelf (Sisson et al., 2002). As a result, the patchiness of offshore benthic assemblages may be explained in part by the habitat heterogeneity provided by shoal features present within an area (Cutter and Diaz, 2000).

Slacum et al. (2006) in an MMS-funded study comparing biological communities of sand shoals and uniform-bottom areas in the Mid-Atlantic Bight reported that: (1) fish and squid within their study area of the Mid-Atlantic either have no preference or prefer uniform-bottom type substrates to sandy shoals during the day; (2) benthic invertebrates have no preference for shoals over uniform-bottom types during the day; and (3) there are diel (day/night) differences in the abundance of pelagic fish using the shoals and reference sites. Slacum et al. concluded that fish could be using adjacent uniform-bottom habitats during the day and move onto the shoals at night to exploit new habitat and that shoals could represent an important resource for fish at night. They also report that species composition was similar between sampling years but species abundances varied.

Few studies have examined the uniqueness of offshore sand shoals as benthic habitats. Cutter and Diaz (2000) reported that the deeper uniform-bottom areas surrounding two shoals off the coast of Maryland – Fenwick Island and Weaver Shoal – were more biologically active and productive than were the tops of the shoals. Our study compared grab samples collected on the shoals to samples collected adjacent to the shoals. As described in Section 3.3.3, no differences in the benthic communities were detected. The shoal features off west Florida are not extremely different in depth from the surrounding seafloor. In addition, sediment characteristics such as grain size and carbonate content were generally similar in samples collected on and adjacent to the shoals.

Some of the literature examining the effects of dredging on offshore biological communities have reported on pits created on flat seafloors and described the biological implications of these features (e.g., Saloman, 1974; Culter and Madadevan, 1982; Saloman et al., 1982; Turbeville and Marsh, 1982; Bowen and Marsh, 1988; Van Dolah et al., 1994). Pits are created by stationary dredges such as anchor dredges. Depending upon their size and depth, pits may have a distinctive impact on the benthic and fish communities as well as the subsequent benthic recolonization and recovery. Pits can act as a sink for fine-grained sediments and contain low DO conditions at the bottom that affect recolonization and recovery and determine the type of benthic community that will become established.

As described in Section 4.2, the trailer suction hopper dredge (TSHD) is the dredge typically used in Federal waters for beach nourishment projects. TSHDs strip off a layer of surface sediment as they move and do not remain stationary or create deep pits. TSHDs generally have dragheads that are typically 2 m wide and create furrows that are 0.25 – 0.5 m deep (Hitchcock et al., 1999). They can pass over an area multiple times creating progressively deeper dredge cuts. In the following sections, we distinguish between any conclusions drawn from literature describing potential biological impacts from operations generating dredge pits and those anticipated from a TSHD.

4.4.1 Benthos

To assess the potential impacts of dredging on offshore benthic populations, it is important to consider the effects in the context of other man-made and natural disturbances that may impact the population as well as the spatial and temporal scales of the impact. For example, offshore benthic communities in the Gulf of Mexico are exposed to large scale disturbances such as periodic storms and Harmful Algal Blooms (HABS) as well as small scale disturbances due to biotic interactions such as organism feeding pits and epifaunal trails.

This section discusses the potential impacts to benthic organisms residing in the offshore areas that may be dredged for beach nourishment projects. Our study essentially characterized the pre-dredge conditions of the sand shoals. There was no post-dredging monitoring. As described in Section 3.2, we were able to collect a subset (3 samples) of T1 samples within the area dredged during the first half of 2006. To assess potential dredging impacts to the benthic communities in the study area we present: (1) an overview of existing literature examining the effects of disturbances on the benthos including recolonization and recovery rates, (2) a discussion of the direct and indirect impacts of offshore dredging, and (3) predictions of the dredging impacts and recovery for the study areas.

4.4.1.1 Overview of Disturbance Effects

The field portion of this study characterized the existing baseline (i.e., pre-dredging) benthic communities within the study areas. As described in Section 3.2, we collected grab samples within the post-dredged portion of T1 but with limited success (i.e., only three samples fell within the dredged area based on an examination of the post-dredge hydrographic survey). There is a relatively substantial body of work examining potential offshore sand borrow areas from previous studies conducted and funded by the MMS:

- Alabama (Byrnes et al., 1999)
- New Jersey (Byrnes et al., 2000)
- Virginia (Hobbs, 2000)
- North Carolina (Byrnes et al., 2003)
- Maryland/Delaware (Diaz et al., 2004)
- East Central Florida (Hammer et al., 2005)

Similar to the current study, these projects characterized the existing or pre-dredge benthic communities and did not include post-dredging surveys. In these previous MMS studies, predictions of dredging impacts and post-dredging recovery were based on existing studies.

Numerous studies have investigated benthic recovery after manmade and natural disturbances (reviews by Rhoads, 1974; Thistle, 1981; Hall, 1994; Thrush & Dayton, 2002). These include studies examining the effects of dredging and other manmade disturbances in estuarine settings (e.g., Kaplan et al. 1975, Van Dolah et al., 1984; Bemvenuti et al., 2005). Offshore studies include investigations of the effects of offshore aggregate mining on macrobenthic communities, especially in, the United Kingdom (e.g., Kenny & Rees, 1994, 1996; Newell et al., 1998, 2004; Hitchcock et al., 2002). Other studies have examined the effects of trawling on offshore benthic communities (e.g., Watling & Norse, 1998; Thrush & Dayton, 2002; Lokkeborg, 2005). There is also a relatively robust body of literature that has examined the effects of natural disturbances (e.g., storms, feeding pits/trails, etc.) on benthic communities and their recovery (Thistle, 1981; VanBlaricom, 1982; Oliver and Slattery, 1985; Hall, 1994; Zajac et al., 1998). These natural disturbances range in spatial scales from centimeters to meters (e.g., feeding pits) to kilometers (e.g., storms and HABS).

There is limited information on the recovery of post-dredging biological communities on the OCS. The Virginia Institute of Marine Science (VIMS) field-tested a physical /biological methodology for offshore dredging operations at Sand Bridge Shoal located offshore of Virginia (Hobbs, 2006). There have been studies examining the effects and recovery of dredged material placement on the OCS (e.g., reports prepared for the USEPA examining Ocean Dredged Material Disposal Sites (ODMDS)). These studies provide useful information in terms of potential benthic recruitment patterns on the OCS.

Spatial and Temporal Scales

Benthic communities vary over several spatial and temporal scales (Thrush, 1991; Zajac et al., 1998; Gray, 2002). Spatial heterogeneity in benthic communities is related to spatial variations in physical conditions such as sediment characteristics, water depth, and hydrodynamics as well as biological factors such as larval recruitment and post-settlement mortality. In addition, benthic community structure is impacted by the spatial extent and/or frequency of disturbance events. Over temporal scales, benthic assemblages demonstrate seasonal and year-to-year differences due to variations in individual species life histories and variability in larval recruitment, post-settlement mortality, and species turnover.

Soft-bottom organisms create much of their habitat's structure ranging from micro-scale changes around individual animal burrows and tubes to larger scale such as sediment reworking by mobile epifauna (Thrush & Dayton, 2002). As a result, they influence sediment stability, water column turbidity, nutrient and carbon processing, and the geochemistry of deeper sediment layers. At small scales such as centimeters, biogenic features such as tubes, feeding mounds, and burrows can play key roles in influencing benthic diversity and resilience (Brenchley, 1981). They also have important roles in the sequestering and recycling processes on the seafloor.

Offshore benthic communities in the Gulf of Mexico are also impacted by large-scale events, both in terms of duration and spatial coverage, which affect community patterns. For example, Harmful Algal Blooms (HABs) are large scale (kilometers) disturbance events that impact benthic communities in the Gulf of Mexico. Off the west coast of Florida, HABs usually occur from late August through November (Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute FWRI website www.floridamarine.org). A large area off west Florida experienced a HAB in the fall 2005 (Figure 4-50) that was caused by the red tide dinoflagellate *Karenia brevis*. The dinoflagellate was trapped in cooler waters under warm, less dense surface water. *K. brevis* decreased oxygen concentrations, which resulted in benthic mortality. This HAB coincided with our first fieldsurvey in early October 2005. This may partially explain some of the low benthic abundances that we recorded. Our CTD results indicated slightly elevated chlorophyll levels at the bottom but did not indicate low DO concentrations (Section 3-3).

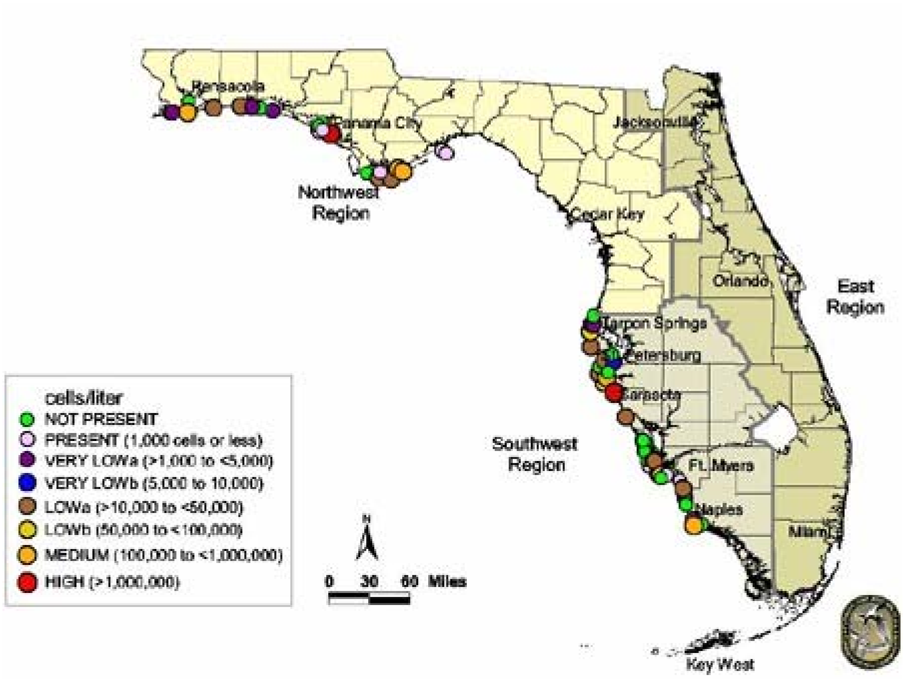


Figure 4-50. ***Karenia brevis*** **counts, October 3 – 6, 2005 (Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute FWRI).**

In addition to HABs, offshore benthic communities within the relatively shallow water depths (approximately 9 – 14 m) in the study area typically experience disturbance from periodic storms. We experienced the frequency of storms in the region during our field operations. Prior to our 2005 sampling period, Hurricane Rita traveled through the Gulf of Mexico from September 17 – 26, 2005 with maximum wind gusts of 180 mph. After our 2005 sampling period, Hurricane Wilma traveled through the Gulf of Mexico and crossed south Florida to the Atlantic from October 15 – 25, 2005 with maximum wind gusts of 185 mph. Additionally, our 2006 sampling schedule was modified because of Tropical Storm Alberto, which was present in the Gulf of Mexico from June 10 - 14.

The extent of dredging operations in the OCS are established over a fixed geographic area and conducted over a specific time period as specified in the lease agreement (see Section 2.5.1.2). The disturbance generated by a dredging operation will be superimposed on a benthic community that has been exposed and will be exposed to a variety of natural disturbances, such as HABs and tropical storms, that occur at various temporal and spatial scales. In addition, there are seasonal and annual variations in recruitment patterns based on the life history of individual species, which will affect recolonization and recovery of the dredged area. Together, these factors make it difficult to predict the precise timing and sequence of benthic community recovery.

As a result, predictions of potential impacts and recovery rates from dredging need to consider the spatial and temporal scales of the dredging operations. In addition, the composition of the existing benthic community and its life history traits, both at the dredge site and in adjacent areas containing potential colonists, and the life histories of the individual benthic species need to be considered. For example, Diaz et al (2004) presented life history information for the benthos at proposed dredging sites offshore of Maryland and Delaware in order to predict potential recruitment and recovery patterns.

Recolonization and Recovery Rates

Benthic recolonization of a disturbed area is dependent on several physical and biological factors at a dredge site. Physical factors include time of year the dredging occurs, duration of dredging, spatial extent of dredged area, local currents/hydrodynamics, and sediment characteristics (e.g., grain size, organic content, chemistry, etc.) of the exposed sediment remaining after dredging, the degree of sedimentation that occurs after dredging, and the type of dredging equipment used. Biological factors include the availability of adult colonists from adjacent undisturbed habitats, availablity of larval and juvenile colonists from the water column, and reproductive and recruitment cycles of species.

Recovery is defined as the return of the community to pre-dredging diversity, abundance, and species composition. Various studies have concluded that benthic communities of comparable pre-dredging abundance and diversity can be expected within dredge sites within several years (e.g., Van Dolah et al., 1992; Blake et al., 1996; Newell et al., 1998; Byrnes et al., 2004). However, investigators have pointed out that although the recolonized post-dredge communities may be similar in abundance and diversity to pre-dredge communities, their taxonomic composition may differ greatly (Kenny and Rees, 1996; Nairn et al., 2004). Byrnes et al. (2004) note that although levels of abundance and diversity of benthos may recover within 1 to 2 years, it may take many years to recover in terms of sediment characteristics and species composition. Wilber and Stern (1992; as cited in Byrnes et al., 2004) concluded that infaunal communities recolonizing borrow sites may remain in an early successional stage for 2 to 3 years or longer. Newell et al. (2004) reported that for areas dredged for aggregate material in the U.K., species diversity generally recovered to within 70-80% of adjacent areas within 100 days and species abundance within 175 days. Newell et al. (1998) presented that recovery times for estuarine muds were approximately 6 to 8 months, sand and gravel approximately 2 – 3 years, and for coarser deposits, 5 to 10 years.

In determining potential benthic recovery rates from disturbances, there is a need to understand the scales of mobility and the processes affecting the successful establishment and growth of potential colonists. In soft-bottom habitats, a range of life stages are typically involved in the recovery processes within a disturbed patch (Whitlatch et al., 1998; Zajac et al., 1998; Thrush and Dayton, 2002). Colonizing organisms are comprised of larvae transported via the water column and post-settlement juveniles and adults actively moving into the area or passively transported via bedload transport (Whitlatch et al., 1998). Small, disturbed areas with a larger edge: surface area ratio should be predominately influenced by adult or post-settlement colonists than larger areas with a smaller edge: surface area ratio. Reproductive and larval development modes are critical to species responses to disturbances across all spatial scales (Zajac et al., 1998). Diaz et al. (2004) note that it is possible to predict the potential nature of recolonizing communities based primarily on the occurrence of other community groups in the vicinity.

Most subtidal benthic assemblages are highly patchy, which may be related to patchy settlement of certain larval year classes due to large-scale subtidal disturbances (Levinton, 1982). A subtidal bottom can represent a mosaic of patches in various development stages following a major disturbance. At small scales, distributions are influenced by the presence of individual structures such as tubes and burrows.

By removing sediment, dredging with a THSD changes the seafloor topography by creating furrows on the bottom. Within the furrows, sedimentary structures such as burrows and tubes are destroyed or buried. As a result, the spatial heterogeneity provided by these structures is removed. In addition, dredging exposes sediments that may, or may not, have similar characteristics (e.g., grain size, organic content, etc.) as the overlying dredged sediment. And the geochemical characteristics of the exposed sediment may also differ. Reworking of exposed sediments by organisms is an important process in benthic recovery after dredging because it promotes diffusion of dissolved oxygen into soft substrate exposed during dredging (Byrnes et al., 2004). If sediments are vertically uniform, sediments exposed by mining/dredging would be similar to those removed, allowing a similar suite of taxa to colonize the dredged sites (Byrnes et al., 2004).

Diaz et al. (2004) noted that the prediction of short-term responses of benthos is more difficult than predicting long-term response because of the asynchronous and naturally variable short-term population fluctuations. They also reported that overall it is probable that larval and juvenile recruitment would be better after a spring/summer dredging than after a fall/winter dredging. Recruitment by adults during any season would likely be regulated by factors such as storms that affect passive transport.

Offshore infaunal community recovery rates after dredging have been reported to range from 1 – 2 years. Jutte and VanDolah (1999) reported the infaunal community offshore of Myrtle Beach, SC recovered in approximately 2 years after dredging was completed.

Posey & Alphin (2002) sampled the benthic fauna of a borrow site offshore of southeastern North Carolina at water depths of approximately 12 – 15 m. The borrow area was part of an old channel. The benthic community in the project area exhibited strong resilience to dredging with little detectable difference between the control and borrow sites one year after dredging. Their results suggest relatively quick recovery from dredging with inter-annual variability explaining more of the observed differences than dredging effects. Dredging was conducted using a TSHD with 1 – 2.5 m of sediment removed. In addition, there was no detectable change after the passage of several hurricanes, though they reported that the possibility existed for undetected long-term effects. The community exhibited strong temporal variability, both among years and seasons, which may have overshadowed any potential long-term dredging impacts.

Barry A. Vittnor & Associates, Inc. (BVA) (1999) reported that the infaunal assemblage in a dredged borrow pit located 3.6 km offshore of Coney Island NY still differed from adjacent reference areas for approximately a decade after dredging ended. They reported that the silt/clay content of the borrow pit was greater than sediment in the reference area. The infauna were dominated by two deposit-feeding spionid polychaetes and deposit-feeding mollusks, which were not recorded at the reference area. They concluded that the persistence of the borrow pit as a feature on the seafloor and the accumulation of fine sediment maintained the differences between the borrow area and reference infaunal communities.

Lotspeich and Associates Inc. (1997) conducted a pre- and post-mining benthic study of a borrow area in Duval County, FL for the Jacksonville District USACE. They reported that troughs, ridges, and depressions observed by divers during the first post-dredging sampling event (less than 6 months after dredging) were no longer visible approximately 1 year after dredging due to a series of severe storms.

They speculated that the storms reworked the sediment in the area to such a degree that the dredging features were eliminated. They reported that differences in the benthic communities between dredged and control areas were "difficult to detect" during the post-dredging monitoring due to areawide declines in species richness and abundance suggesting other impacts such as storms may have affected the area over the length of the study. They also reported that strong temporal changes in benthic infaunal abundance and species richness greatly exceeded spatial variance.

Hobbs (2006) conducted pre- and post-mining benthic studies of a borrow area on Sandbridge Shoal, VA and found little discernable difference between areas that were disturbed by sand mining and nearby areas that had not been mined. Although substantial quantities of sand were removed from the shoal, no negative environmental impacts were observed for benthos or demersal fishes. Differences in benthic abundance between years were observed both within and beyond the mined areas, indicating that inter-annual variability has a greater influence on benthic abundance than sand mining.

Table 4-2. Reported Macrobenthic Recovery Rates at Offshore Dredged Sites

Type of Impact/ Disturbance	**Location**	**Recovery Time**	**Source**
Dredged Borrow Pit	Offshore Coney Island NY	10+ yrs	BVA (1999)
Dredged Borrow Pits	Offshore Panama City, FL	~1 yr	Saloman et al (1982)
Aggregate Mining	North Norfolk, UK	>2 yrs	Kenny & Rees (1996)
Aggregate Mining	Offshore e. & s.e. coasts, UK	~8 yrs	Cooper et al. (2005)
Aggregate Mining	Isle of Wight, UK	100 – 175 days (pop'n density, spp diversity) >18 months (biomass)	Newell et al. (2004)
Hydraulic Clam Dredge	Scotian Shelf (70-80m), Nova Scotia	>3 yrs	Gilkinson et al. (2003)
Dredged Borrow Area	Offshore Duval County, FL	< 1 yr	Lotspeich & Associates (1997)
Dredged Borrow Area	Offshore Belmar to Manasquan, NJ	1.5-2.5 yrs	USACE (2001)
Dredged Borrow Area	Offshore Great Egg Harbor Inlet, NJ	~2 yrs	Scott & Kelley (1998)
Dredged Borrow Area	Offshore n. coast NJ	~1 yr abundance ~1.5 – 2.5 yrs biomass	Burlas (2001)
Dredged Borrow Area	Offshore Myrtle Beach, SC	~ 2 yrs	Jutte & VanDolah (1999)
Dredged Borrow Area	Offshore southeast NC	~ 1 yr	Posey & Alphin (2002)
Dredged Borrow Area	Offshore Virginia Beach, VA	< 1 yr	Hobbs (2006)

Successional Patterns

Benthic succession has been relatively well-studied in estuarine subtidal and intertidal environments (e.g., Pearson & Rosenberg, 1978; Thistle, 1981; Zajac & Whitlatch, 1982; Whitlatch et al., 1998). Previous MMS studies (e.g., Byrnes et al., 2000), have described successional stages and patterns in soft-bottom habitats which primarily have been studied in silt-clay dominated systems. There is very limited information on successional patterns for offshore shelf communities and whether or not these sand-dominated habitats follow the silt-clay successional model. Although not well-established in shelf communities, various studies indicate that benthic disturbances tend to favor opportunistic species which have high reproductive rates and are small, mobile, and short-lived. Later successional stages tend to be long-lived, large, and slow growing. For disturbances such as dredging, where habitat structure and heterogeneity are reduced and large areas of habitat are modified, slow-growing and slow-reproducing species will be strongly affected. Over time, repeated intense disturbance will select for species with appropriate facultative responses, and communities are likely to be dominated by juvenile stages, mobile species, and rapid colonists (Thrush & Dayton, 2002).

The response of opportunistic species to disturbance depends on the magnitude or scale of disturbance and on life history traits such as mobility, reproduction timing, mode of development, and dispersal methods (Levin, 1984). The Pearson and Rosenberg model describes a gradual succession of benthic communities along gradients of decreasing disturbance from opportunists to a climax-community with deep-burrowing organisms (Pearson & Rosenberg, 1978; Norkko et al., 2006). The Pearson and Rosenberg model was developed using study results from organic enrichment of muddy subtidal sediments. Early colonists have life history traits such as small size, rapid growth, high reproductive capacity, and good dispersal capacity that facilitate rapid responses and large increases in abundance in disturbed areas. Similar patterns may hold for continental shelf benthos dominated by sand substrate. However, these systems have relatively low organic content and are exposed to frequent large-scale disturbances.

4.4.1.2 Dredging Impacts on Benthos

The primary, direct impacts on the benthic community from dredging sand from offshore borrow sites result from the removal, suspension, dispersion, and deposition of sediment. During sediment removal, dredging entrains infauna and epifauna living within and on the sediment. Dredging typically results in an immediate and significant decrease in the abundance, biomass, and number of benthic organisms.

Additionally, dredging causes suspension of sediments, which increases turbidity over the bottom as a benthic plume. The plume is dispersed by currents in the area and can extend for kilometers (Dickinson and Rees, 1998). Suspended sediments settle and are deposited nearby or some distance from dredged sites. Turbidity may be a minor issue with offshore shelf sediments, which consists primarly of sands with small amounts of fine-grained sediment such as silts, clays, and organic matter.

Hall (1994) described the possible direct effects of physical disturbance, such as dredging, at various levels of the benthic community organization. The effects may be the result of sediment removal, suspension, dispersion, and depositional processes.

Table 4-3. Possible Effects of Dredging on Offshore Benthos

Level of Organization	Possible Effects
Individual	Increased probability of death or injury
	Energetic cost of re-establishing
	Effect on reproductive output
	Effect on food availability
	Exposure to predation or displacement
	Provision of colonizable space
	Competitive release
Population	Changes in density
	Changes in recruitment intensity and/or variability
	Changes in dispersion patterns
Community	Changes in species diversity
	Changes in overall abundance
	Changes in productivity
	Changes in the patterns of energy flow or nutrient recycling

Source: Hall (1994)

Most adult infauna have limited motility. Tube-dwelling species are generally sedentary but can relocate over short distances on the order of centimeters. Errant species move but also over small distances. In addition, some species may enter the water column and be transported by currents over relatively larger scales such as meters. Storms can suspend adult infauna in the water column and transport them over relatively large distances (Dobbs and Vozarik, 1983; Committo et al., 1995).

4.4.1.3 Sediment Removal

Dredging physically removes sediment, or benthic habitat, with any infauna and epifauna that cannot avoid the dredge from a location. The majority of benthic infauna resides in the upper 15 cm of sediment. Most dredge cuts by a TSHD draghead are 0.25 – 0.5 m deep. As a result, the majority of benthic organisms will be permanently removed or displaced from the footprint of the dredge.

Dredging results in:

- Creation of furrows and depressions from the TSHD resulting in changes in sediment topography and the lowering of topographic high features.
- Changes in local hydrodynamics due to changes in bottom topography.
- Removal of substrate and exposure of underlying sediment with potentially different characteristics than the pre-dredged surface sediment such as grain size distribution, compaction, cohesion, total organic content, and DO levels.

- Removal of sedimentary structures such as burrows and tubes.
- Removal of potential benthic prey organisms for commercially or recreationally important fish.

The potential sand borrow areas examined during this study extended a few meters off the seafloor. Dredging would alter the local topography by creating furrows or trenches on these shoals. With the change in local seabed topography, local hydrodynamics would change which may affect the distribution of benthic organisms. Larvae and adults may be passively carried by currents. Hydrodynamics can affect larval settlement and transport at several scales (Eckman, 1983; Butman, 1987). In addition, hydrodynamics may affect the distribution of food resources, which would impact benthic distribution.

In addition to physically removing surficial layers of sediment as well as the benthic community, dredging would expose sediment that has different physical and geochemical properties than the pre-dredge sediment. It would expose anaerobic sediment that would likely affect recolonization by the benthos (Diaz et al., 2004). In addition, disruption of the sediment enhances the upward flux of nutrients by releasing pore-water nutrients as a pulse, rather than a steady release controlled by bioturbation (Pilskaln et al., 1998; Thrush & Dayton, 2002). The change in the surficial sediment characteristics may change its suitability for burrowing, feeding, or larval settlement for the benthos.

4.4.1.4 Sediment Suspension, Dispersion, and Deposition

In addition to removing sediment, dredging also suspends and disperses sediment at two primary points in the operation – at the draghead and discharge of overflow. As described in Section 4.2.1, a TSHD is the typical dredge type used for offshore sand dredging. A TSHD is designed to maximize the concentration of sediments in the pump. The disruption to the seafloor caused by the draghead can result in suspension and plume development (W.F. Baird & Associates Ltd., 2004). In addition, some of the sediments pumped into the dredge hopper do not settle out of suspension, typically the fine sands and silts, and are discharged through one or more spillways.

Water, displaced from the hopper and discharged, can have significant initial momentum resulting in a body of water, denser than the surrounding water and descends towards the seafloor (Baird, 2004). The initial rapid descent of the plume is referred to as the dynamic phase and dynamic plume. The zone of influence of the dynamic plume can vary considerably depending on the magnitude and direction of the current flow; dredge speed, initial density of the sediment/water mixture, and initial momentum of the mixture.

Sediment that is stripped from the plume into the water column during the descent of material or as the dynamic plume impinges on the seafloor or during the flow of material along the seafloor will form a passive plume of material that will slowly disperse with the mixing effects of currents and waves. The concentration of the passive plume will decrease over time with the settling of sediment particles from turbulent diffusion and shear dispersion. The zone of influence for the passive plume can be several kilometers or more and is dependent on the magnitude of tidal currents and the magnitude of sediment releases from the dredging operation (Baird, 2004). Suspended sediment concentrations within the plume can be hundreds of milligrams per liter above background near the dredger decreasing to tens of milligrams per liter above background as the distance from the dredger increases (Baird, 2004).

Dredge plume sediments that have been deposited on the seabed may become resuspended if the local currents exceed thresholds for sediment erosion. As a result, these sediments may become even further dispersed (Baird, 2004).

Sediment suspension and redeposition may impact the immediate benthic community and adjacent areas due to burial of adults and/or recruits and/or impacts to suspension feeding (e.g., Miller et al., 2002). Dredging also uncovers and displaces benthic organisms into the water column, exposing the benthos to predators.

Dredging produces turbidity in the surrounding waters. Turbidity decreases light penetration and alters the wavelength of light capable of reaching the seafloor which may decrease the productivity of benthic alga and other primary producers in an area. Light also affects the dispersal and settlement of larvae (Thorson, 1964). Turbidity may also adversely impact available food for the benthos. Turbidity reduces visibility for predators that utilize sight to feed.

Turbidity may adversely impact filter feeders by clogging feeding appendages and apparatus with inorganic particles that have little or no nutritional value. Increased sediment concentrations in the water column may also negatively impact benthic organisms through tissue abrasion, slowed growth, and reduction in optimal feeding or foraging conditions. Through its physical disturbance of the sediment, dredging may release nutrients and other organic matter such as carbohydrates, fats, and lipids into the water column from damaged organism tissue due to entrainment and fragmentation from dredging (Coastline Surveys Limited, 1998). The suspended matter may result in localized hypoxia or anoxia due to increased oxygen consumption (LaSalle et al., 1991).

Horizontal sediment movement is relatively unimportant to benthic infauna. The vertical movement of the bed, through erosion and deposition, is critical (Miller and Sternberg, 1988; Miller et al., 2002).

Depending on hydrodynamic conditions at the site, the sediment suspended by the dredging operation, both at the seafloor and from barge or hopper overflow, will generally settle in close proximity to the dredged site or at some distance from the site. Depending upon the magnitude, sediment deposition may suffocate and bury the benthic community present. Mobile soft-bottom organisms have the ability to migrate vertically to the surface through newly deposited sediment (Maurer et al., 1986). Sessile hard bottom organisms can be particularly sensitive to heavy sedimentation loads since they cannot relocate. As described in Section 3, some sessile organisms such as sponges and gorgonians were observed in the areas off the shoals and were captured in some of the trawls conducted in the adjacent areas. However, this study area is exposed to storms and, as such; the benthic organisms experience sediment resuspension and deposition on a frequent basis.

As noted in previous MMS reports, dredging effects are not limited to the borrow site (Diaz et al. 2003). Impacts from sediment suspension, dispersion, and deposition may be evident hundreds of meters from the dredged site. Studies have shown decreases in infaunal abundances adjacent to a dredged area as well as enhanced benthic diversity and abundance due to the release of organic nutrients from the dredge plume (e.g., Newell et al., 1998).

If sedimentation is similar to natural events, then community responses are expected to follow natural seasonal and successional trends (Miller et al., 2002). If sedimentation exceeds natural thresholds, then impacts may involve total loss of the community and subsequent colonization by pioneer or opportunistic species and be driven by an entirely different suite of ecological processes that may lead to dramatically altered benthic communities (Miller et al., 2002).

4.4.1.5 Predicted Dredging Impacts to Benthos within the Study Area

As noted in previous MMS studies (e.g., Byrnes et al., 1999; Diaz et al., 2003; Hammer et al., 2005), determining the impacts of offshore dredging and the subsequent recolonization and recovery is difficult because most benthic communities are complex associations of organisms that demonstrate a large amount of spatial and temporal variability over a variety of scales. Additionally, because of the dynamic nature of the benthic communities and their variation over time, recovery of the dredged area does not mean that the benthic community will return to pre-dredging conditions such as species abundances and composition. Recovery means that the dredged area would return to similar species composition as similar non-dredged areas in the vicinity at a point in time in the future. Benthic communities on the west Florida shelf are exposed to a variety of large-scale disturbances such as storms and HABs that effect community structure. As noted in Section 3.3.3, abundances, species numbers, and diversity in dredged areas may reach background levels relatively rapidly, however, species composition may require a longer period of time.

Dredging the sand shoals in this study area will result in an immediate decrease in the abundance, diversity, and biomass of benthic organisms within the dredged footprint. Because the benthic assemblages on the sand shoals examined were similar to the assemblages in the adjacent areas off the shoals and the spatial extent of the dredged area is small compared to the broad area of the west Florida shelf, it is expected that there would be a negligible impact on the ecosystem. In addition to larval recruits from the water column, the surrounding areas (that are not targeted for dredging) would supply the potential adult colonists with the area disturbed by the dredging operation. Similar to conclusions reached in previous MMS studies, the high densities and fecundity of the benthic populations in the area together with the relatively small area of impact would preclude significant long-term effects on the benthic populations (Byrnes et al., 2003; Hammer et al., 2005).

Slow-moving and burrowing epibiota inhabiting the study area include echinoderms such as sand dollars and brittle stars and decapod taxa, and local populations of these types of benthic organisms would most likely experience a reduction in density due to sediment removal and entrainment in the suction dredge. Motile epifauna generally are migratory and are not restricted to the borrow areas.

The timing of dredging will be important because many benthic species have distinct reproductive and recruitment periods (Diaz et al., 2004; Hammer et al., 2005). Recovery will be primarily from larval recruitment and adult immigration. Therefore, recovery should be most rapid if dredging is completed before seasonal increases in larval abundance and adult activity (Herbich, 1992; Hammer et al., 2005).

As described in Section 3.3.3, the benthic assemblages within the study area were generally dominated by small bodied, deposit-feeding species, such as the spionid polychaetes *Prionospio* spp. and *Spio pettiboneae*, and the molluscs *Caecum johnsoni*. The dominance of this community type throughout the study area may be function of the frequent and periodic large scale disturbances that occur on the west Florida shelf. These species live at the sediment surface. Byrnes et al. (2004) posit that the pioneering species, which colonize the dredged area first, share several ecological traits such as a tendency to confine their activities to the sediment-water interface, possibly because subsurface conditions cannot support a significant number of organisms. They also note that the subsurface conditions will change over time after dredging possibly by the bioturbation activities (e.g., burrowing, tube building, feeding etc.) of early colonizers and becomes suitable for deposit feeders and mid-depth burrowers. The absence of mid-depth burrowers and deposit-feeders is interpreted to mean that an area is still in a state of recovery (Byrnes et al., 2004).

Based on results of other studies, it is expected that recolonization of the dredged area should begin soon after dredging activities end from larval settlement from the water column and adult and post-settlement juveniles not entrained by the dredge as well as from adjacent areas. In addition, as previously noted, studies have indicated that although the abundance, species, and biomass of benthic infauna may approach pre-dredging levels in a relatively short time after dredging (< one year in some cases) community composition may take much longer.

An additional consideration in predicting the potential benthic impact and recovery rate is the length of time that the dredging operation takes place. For example, the dredging operation at the northern portion of T1 began in February 2006 and ended in May 2006 and lasted over 90 days. With dredging occurring over a large area, some portions of the dredged area may be undergoing recovery while other portions are being impacted. As such, dredging is not like a storm or HAB event that affects a large area simultaneously. Therefore, meaningful future post-dredging monitoring programs should be aware of when a specific area was dredged, what specific areas were dredged, and the duration of the dredging operation.

Within days after dredging has ended, it is expected that the dredged area should be initially colonized by opportunistic species – through both larval settlement and adult migration. It is expected that these colonists would be comprised of certain species of polychaetes, crustaceans, and bivalves. Initial larval recruits likely would be dominated by deposit feeding, opportunistic taxa, such as the *Prionospio* spp. and *Caecum johnsoni* that were dominant in the samples collected during the June 2006 survey. These species are well adapted to environmental stress and can exploit suitable habitat when it becomes available. Later stages of the benthic recolonization will be more gradual and involve taxa that generally are less opportunistic and longer-lived. Immigration of motile annelids, crustaceans, and echinoderms into impacted areas also will begin soon after dredging. As noted by Newell et al. (1998) and Diaz et al. (2004), dredging portions of each shoal and leaving areas undredged will ensure that a supply of non-transitional, motile taxa will be available for rapid migration into dredged areas.

As described in Section 2.3, the west Florida shelf is sand starved. Thus, it is unlikely that the furrows, trenches, and dredge cuts will be refilled with new sediment transported from other sources off the shoal. However, periodic storms are likely to redistribute sediment and, over time, restore the shoals to their pre-dredged morphology. Additionally, cores taken on the T1/T2 shoals by Finkl et al. (2004) indicate that the sediment on the shoal is vertically uniform for grain size. Therefore, sediment exposed during dredging should be similar to that in the pre-dredged condition and benthic community that becomes established should be similar to that in the predredged condition.

Hammer et al. (2005) noted that seasonal variability should be considered when considering potential impacts due to dredging. The timing of dredging would be less critical for minimizing the impact on infauna than for other faunal categories of concern (e.g., key pelagic species such as marine mammals or sea turtles) due to the great abundance and reproductive potential of infaunal populations. Many numerically dominant infaunal taxa inhabiting the study area are known to exhibit either year-round or late winter-early spring periods of recruitment. Because of these patterns of recruitment and lower winter densities, removal of sand between late fall and early spring would result in less stress on benthic populations.

4.4.2 Fishes/Macroepifauna

Fish catches in otter trawls were numerically dominated by demersal teleost species with a known affinity for open sand and mud substrates. In fact, the four sea robin and four flatfish taxa identified (all strict benthic associates) together comprised 72% of the 2,317 individuals taken. Trawls contained few fish species of direct commercial or recreational value. Most notably, only seven hardbottom-associated species managed under the Gulf of Mexico Fishery Management Council's reef fish complex were collected, and of these only juvenile grunts (*Haemulon* spp.) were common. No fishes listed as endangered or threatened under the Endangered Species Act (i.e., smalltooth sawfish or gulf sturgeon), nor those prohibited from harvest by the State of Florida or NMFS were collected. Macroinvertebrate trawl catches included a diverse assortment of decapod crustaceans and echinoderms and lesser numbers of stomatopod crustaceans, cephalopod, and gastropod molluscs. Economically valuable penaeid shrimp were commonly taken (20% of catch) as well as small numbers of *Callinectes* spp. (blue) crabs.

The composition of trawl catches is undoubtedly influenced by sample site selection. Because the sand resource areas of interest were identified by their elevated deposits of beach quality sand, they are less likely to offer the exposed limestone hardbottom substrates necessary to support a high diversity of reef-associated taxa. Nonetheless, repeated damage to the trawl occurred during tows adjacent to Siesta Shoal on Cruise 1 and Shoal T2 on Cruise 2 suggesting that substantial hardbottom is present in the vicinity of these borrow sites. Therefore, species richness in the area is undoubtedly much higher than indicated by trawling alone. Additional sampling at other times and with other gears (e.g., gill nets, longlines) would likely produce a much larger species list and yield reef-associated and pelagic teleost and elasmobranch fishes with economic importance.

Results of the MDS analysis indicate that greater differences in the fish and macrocrustacean species assemblage occurred between seasons (i.e., cruises) than between or within individual sites. The presence of large numbers of fish and macroctustacean taxa in the study areas is expected because these taxa susceptible to trawls possess considerable tolerances in water temperature, salinity, and depth, and thus range widely over the Florida continental shelf and throughout the western Atlantic Ocean (Wenner and Wenner, 1988; Pierce and Mahmoudi, 2001; Carpenter, 2002). However, many of these taxa have distinct periods of spawning and recruitment with some undertaking temporally predictable estuarine-shelf migrations. Although life history strategies vary considerably among species, reproductive activity of many shelf fishes peaks during warmer months and wanes as temperatures drop in winter (Able and Fahay, 1998). This pattern may explain why 42 taxa (often represented by recently recruited juveniles) were collected during Cruise 2 (June 2006) compared to only 23 on Cruise 1 (October 2005) and why fish densities during Cruise 2 were much higher.

Dietary analyses of numerically dominant demersal fishes illustrate the importance of infaunal and epifaunal invertebrates to the food web of open sand fish communities. Lancelets and crustaceans, especially shrimp, served as dominant forage for the seven fishes in which prey items were identified. Many other demersal fishes abundant on the west Florida shelf (e.g., drums, croakers, mojarras, porgies, and grunts) are known to exhibit a similar reliance on invertebrate prey.

Ichthyoplankton catches were dominated by larval gobies, anchovies, and herring, representing 47%, 29%, and 11% of the catch, respectively. Larvae of these families are among the most common in estuarine and shelf waters throughout Florida, and given their long pelagic stages, their distribution is likely independent of local substrate types. Ichthyoplankton samples typically demonstrate considerable variability in species composition and abundance even at a single location (Richards, 2006). In the present study, plankton collections were limited and thus inadequate to fully describe fish spawning or recruitment in the region. Nonetheless, it is notable that only one larva of a managed reef species (an unidentified snapper, *Lutjanus* sp.) was taken.

Coastal dredging operations affect marine organisms in a number of ways. Short-term impacts typically consist of ephemeral changes in water chemistry, habitat quality, or organism behavior derived from the mechanical disturbance of the seafloor during the act of dredging. While often harmful, these impacts are usually localized and dissipate rapidly once dredging activity ceases. Long-term impacts typically consist of more permanent alterations in benthic substratesand local hydrodynamics, or disruptions of vulnerable life history stages of marine species. This section summarizes the potential threats specific to fish and macroinvertebrate communities that may arise from dredging operations along the west Florida continental shelf including: (1) entrainment, (2) behavioral alterations, (3) turbidity and sedimentation, (4) changes to soft-bottom bathymetry, and (5) risks to hardbottom habitats. The magnitude of impacts and temporal windows (if any) when impacts can be minimized are also discussed. Much of this information is derived from other regions where dredging has been more thoroughly studied, however, even where dredging impacts to biota have received considerable scrutiny, long term consequences to habitat suitability and population-level dynamics of marine organisms often remain poorly understood (National Research Council, 1995). This review does not address impacts to nekton at the site of sand redeposition (e.g., shoreline). Renourishment of Florida beaches can have considerable negative biological consequences to fish and their shoreline habitat (Lindeman and Snyder, 1999) but impacts are site specific, dependent on the size of renourishment area, dredging protocols, local wave and current characteristics, and proximity to nearshore reefs and inlets.

(1) Entrainment

Entrainment refers to the physical uptake of organisms during dredge operation. Dredge entrainment of fish and invertebrates has been a concern for many years because in most instances, associated mortality rates are likely to be high. Entrainment rates are influenced by a number of factors including the type of dredge used, speed and volume of dredge operations, water depth, as well as animal size, mobility, and behavior. Benthic macroinvertebrates may be especially prone to entrainment. Dungeness crab (*Cancer magister*) off the coast of Washington State, for example, is susceptible to entrainment mortality because they congregate in deep navigation channels that necessitate repeated maintenance dredging (McGraw et al., 1988; Larson and Patterson, 1989). Female blue crabs (*Callinectes sapidus*) are considered vulnerable since egg-bearing individuals overwinter within sediments and may be too lethargic to avoid uptake. Sand shrimp (*Crangon* spp.) and commercially valuable penaeid shrimp are also thought to be vulnerable (although quantitative information regarding shrimp entrainment and mortality is lacking) as are sessile bivalves such as oysters, mussels, clams, and scallops (Reine and Clarke, 1998).

Fishes are also regularly entrained in dredges although usually in relatively low numbers (Reine et al., 1998). Although larval and juvenile fishes are often of greatest risk of entrainment due to their limited mobility and swimming strength, fishes as large as small sharks are known to be entrained. In one of the more complete studies, McGraw and Armstrong (1990) recorded entrainment of 28 fish species in Grays

Harbor, WA, at species-specific rates ranging from <0.001 to 0.594 individuals per cubic yard with highest entrainment suffered by burrowing or otherwise demersal fishes. To date, however, the greatest concern has been directed towards anadromous sturgeon, salmon, shad, and striped bass whose spawning and recruitment success may be dependent on their ability to successfully bypass estuarine and riverine dredging operations and associated turbidity plumes. Entrainment-related mortality of fishes has not been adequately assessed in open coastal waters.

On the west Florida continental shelf, the distribution of individual fish and macroinvertebrate species is largely determined by water depth, temperature, and salinity with most species ranging widely throughout the study area (Pierce and Mahmoudi, 2001). Therefore, entrainment during offshore sand dredging operations, even if associated mortality is high, is likely to have minimal population level impacts for most taxa. Fish entrainment should be a localized, short-term concern for only a few families such as burrowing eels and gobies as well as slow moving demersal taxa including sea robins, flatfish, and batfish. Further, given the scarcity of economically valuable reef fishes in trawl samples, entrainment mortality is expected to have negligible negative economic impact on coastal fisheries. Entrainment of penaeid shrimp may be more of a concern, although density documented within borrow site boundaries (mean 20.5 shrimp per ha averaged across sites) was not especially high. Some entrainment should be anticipated year round but rates may be elevated during periods of high juvenile fish recruitment, likely during the spring and summer.

(2) Behavioral Alterations

Fish use underwater sound pressure waves to locate food and detect the presence of predators. In addition, many coastal fishes are soniferous, using sound to communicate, especially during courtship and spawning. In fact, in the current study, 26 of the 50 taxa collected in trawls (89% of all individuals) are representatives of soniferous fish families including sea robins, cusk eels, and groupers, some of the most prodigious sound producers in Florida coastal waters. Certain macroinvertebrates such as alpheid snapping shrimp and barnacles also produce sound. It has been demonstrated that biological sounds are often considerable at certain times and places and are known to attract settlement stage fish larvae to reefs (Leis et al., 2003; Simpson et al., 2005).

While behavioral alterations of nekton resulting from anthropogenic sound pollution including dredging is poorly studied, it is possible that foraging, spawning, and recruitment success of fishes and macroinvertebrates will be impacted in the immediate vicinity of dredging operations, causing some organisms to relocate. It is also possible however that the physical presence of dredging infrastructure and light produced during nighttime operations may actually attract other species to the vicinity. Behavioral alterations from sound, light, and structure should be expected year round but are localized and will cease once dredging has completed.

(3) Turbidity and Sedimentation

Increased turbidity is often generated directly at the site of sediment excavation or as slurry overflow or dewatering from hopper dredge barges. Wind, waves, and strong directional currents can also resuspend fine particles that accumulate in dredge areas for many years after excavation has ceased. Turbidity may alter the trophic dynamics of an area by reducing the feeding efficiency of planktivorous fish (Hecht and van der Lingen, 1992; Benfield and Minello, 1996) and may clog feeding structures of infaunal taxa, leading to a reduction in benthic prey resources. In rivers and estuaries, turbidity plumes may influence

spawning migration of anadromous fishes (although some estuarine turbid zones are recognized as high value habitat for larval fishes due to high rates of survival and growth; North and Houde, 2001). Turbidity can also directly influence fishes by irritating or clogging gill membranes and sediment deposition can coat eggs of deposit spawners, hindering egg respiration and increasing mortality.
The direct impact of turbidity on mortality, growth, and spawning behavior for continental shelf fishes and macroinvertebrates is largely unstudied but is likely a minimal concern at the three proposed borrow sites since most fish are mobile enough to escape or avoid areas of highest turbidity. Further many shelf fishes, especially those who also utilize estuaries, are likely adapted to relatively high ambient turbidity levels. Sedimentation also likely poses minimal threat to fish spawning success because most shelf taxa, including virtually all valuable fishery species, produce pelagic eggs. Possibly the largest turbidity-related threat to fish and macrocrustaceans are the consequences of sediment resuspension and redeposition on benthic filter feeding prey, a process that may alter the forage base for several years.

(4) Changes to Soft Bottom Bathymetry

Sand shoals are expected to support an ichthyofauna dissimilar to the surrounding seafloor. Not only will many shoals possess differing sediment types and associated infaunal communities, they may also serve as shallow-depth refugia from predators, physical landmarks on which fish assemble or spawn, and may also be areas of high turbidity that enhance survival of small-bodied prey taxa. In U.S. Atlantic waters, the fisheries value of sand shoals has received some scrutiny as a result of MMS interest in mining offshore sand deposits (e.g., Byrnes et al., 1999; 2003; Hammer et al., 2005; Slacum et al., 2006) and shoals have previously been identified as valuable habitat for fishes including cod (Fahay et al., 1999) and juvenile sharks (Rountree and Able, 1996; McMillan and Morse, 1999).

The physical removal of bottom sediments during dredging results in an immediate reduction in the biomass, density, and diversity of infauna and epifauna. These organisms serve as essential prey for many small-bodied benthic fishes, as demonstrated in gut content analyses conducted in the present study. Loss of this forage base during dredging will have an immediate consequence on the survival and growth rates of benthic fishes in the immediate vicinity of dredge operations, with the most severe impacts apportioned to those species with limited mobility. Further, borrow sites are often recolonized by differing benthic communities, a factor that may eliminate some selective benthic feeders, resulting in lower local diversity of demersal fish and macrocrustaceans. In certain cases, however, depressions left behind may serve as sites where fish aggregate or seek thermal refuge (Vose et al., 2005).

While trawling is an effective method to sample shoal fish faunas, the expense and logistics of this method is often high so sampling consists of few, widely spaced efforts. Thus, only gross changes in community structure may be detected. Data collected from limited trawling in the present study provide no indication of a unique faunal assemblage inside proposed sand borrow sites and the most common species collected are small-bodied widely distributed demersal taxa of little commercial or recreational fishing value. Thus, while impacts to the fish fauna from sediment alteration at dredge sites are largely unavoidable regardless of dredging method or season, these impacts should be largely limited to the dredge site itself.

(5) Damage to Hardbottom Habitats

Dredging impacts to hardbottom substrates have been a concern for many years. Damage to reefs are caused by the dredges themselves, barge anchors and mooring chains, and sand discharge pipelines. These dredging impacts destroy the coral and associated invertebrate communities and reduce reef rugosity. These changes often reduce reef carrying capacity, alter fish spawning behavior, and shift the communities toward algal dominated systems. In Florida, much dredging-related reef damage is related to sand deposition on nearshore reef structures. Lindeman and Snyder (1999) noted a dramatic decline in both fish species and individuals after the burial of a nearshore reef structure in southeast Florida.

The presence of hardbottom limestone outcroppings adjacent to Tom's Hill 2 and Siesta Shoals is supported by damage to otter trawls during Cruise 1 and Cruise 2. These substrates should be expected to harbor a diverse assortment of reef fishes and macrocrustaceans, many of which are the target of recreational and commercial fishermen throughout the region. However, risk of damage to this habitat due to sand dredging is minimal since hardbottom resources within the study area boundaries have been mapped and can easily be avoided.

4.4.3 Sea Turtles

Protected species present

Of the five species of marine turtles known to frequent coastal and offshore waters of Florida, three are likely to occur in the vicinity of selected study areas; loggerhead, green turtle, and the Kemp's ridley. According to FWC the relative abundance of sea turtle species present in coastal waters corresponds to nesting data. For sixteen years from 1990 to 2006, 83, 814 loggerhead nests were counted on southwest coastal beaches (FWC, 2007). By comparison the nest counts were much fewers over a longer time frame for green turtles (200 nests) and the Kemp's ridley (1) from 1979 to 2006 (FWC, 2007). Stranding records are another indicator of species presence. Stranding data from 2005 (FWC, 2006) confirms all five species are present in the study area. Leatherbacks and hawksbill turtles may be present for brief periods of time if at all due to their different habitat preferences and their migratory nature. One leatherback nest was counted in Sarasota County and no hawksbill nests were noted in any of the counties onshore of the study area from 1979-2006 (FWC, 2007).

<u>Potential injuries to sea turtle or sea turtle habitat</u>

The potential impacts to sea turtles by offshore dredging activities include entrainment, disturbance to benthic foraging habitats and disruption of the prey base, interference with underwater resting habitats, noise disruption, and physical harm from contact with vessels and dredge equipment. Seasonal activity in the study area varies with species; yet all are present in greater numbers during nesting season from April to September. During this same period juvenile and subadult loggerheads, Kemp's ridleys, greens, and leatherbacks may be encountered.

Direct takes of individuals entrained by hopper dredges is well documented (Mansfield and Musick, 2003; Dickerson et al., 2004). As the suction tube of a hopper dredge is pulled on the ocean floor turtles are pulled into the intake tube while lying on the bottom or when startled they dive in an attempt to move away from the dredge. Rarely do turtles travel from the dredge pipe onto the catch screen without death or injury. A total of 360 confirmed loggerheads were taken by hopper dredges between 1980 and 2003. Hopper dredges in the U.S. have a record for the cause of 50 takes of greens and 37 takes of Kemp's ridley turtles between 1980 and 2003 (Dickerson et al., 2004).

Disturbance to benthic foraging habitats and disruption of the prey base is less well documented. Sea turtles feed on benthic invertebrates, fish, crabs, jellyfish, sponges, and seagrasses. Loggerheads were observed during the October 2005 and June 2006 field surveys and are most likely to occur on or near the shoal sites where they consume mainly benthic fauna, such as crabs and molluscs. Loss of this prey base could impact a number of individuals, such as loggerheads. Marine turtles, particularly loggerheads, show some foraging site fidelity. Therefore, turtles occupying or feeding at the shoal sites may be affected during and after dredging operations if benthic fauna are marginalized. The relief in the selected shoal sites is much greater than the surrounding bottom, which is attractive to loggerheads who seek out similar topographic features, thus increasing the likelihood that loggerheads will be present during dredge operations. Dredging activity in and near floating *Sargassum* seaweed beds used by hatchling green turtles as nursery habitat (MTSG, 2004) may disturb or remove potential juvenile turtle habitat, and/or harm hatchlings inhabiting them.

Noise impacts to sea turtles are yet undefined and may vary with species and cannot therefore be assessed or mitigated. Earlier experiments showed loggerhead turtles responded to low-frequency sounds within the range of 250 to 1000 Hz and they are able to filter ambient noise (Moein, 1994). These experiments, which were intended to further the technological development of acoustic deflectors for turtles during dredging and to assist in disease diagnosis, had mixed results. Lenhart et al. (1994) found no change in directional swimming approach or avoidance when turtles were exposed to low-frequency sounds, the, turtles stayed on their original course. Controlled exposure experiments on captive turtles found an increase in swim speed and erratic behavior indicative of avoidance from seismic airgun sound levels of 166–176 dB (O'Hara and Wilcox, 1990; McCauley et al., 2000). Weir (2007) was unable to document any impact of sound at certain frequencies on turtles during a study of seismic airgun sound in ocean waters in the presence of mixed turtle species.

Collisions with vessels are a concern for marine turtles because they mate, bask, and forage on the surface (NCR, 1990). From 1986 - 1993, about nine percent of stranded sea turtles (living and dead) off the coast of Florida had propeller or other boat strike injuries. Vessel strikes are an important cause of sea turtle mortality (Lutcavage et al., 1996). Death from prop damage is documented in standing data for counties onshore of the study areas (STSSN, 2006).

Sea Turtle Mitigation Measures

Mitigation measures for dredge operations have been adapted over the years to include protective equipment, operational modifications, pre-dredge surveys and relocation of turtles prior to dredging. In 2006, Coastwise Consulting, Inc. successfully relocated 87 sea turtles (1 green and 86 loggerheads) before the Collier County beach fill project and no turtle takes were reported during dredging. Studies completed for the U.S. Army Corps of Engineers on modified hopper dredges have reported reduced turtle mortality due to fewer takes during dredging operations http://www.saj.usace.army.mil/pd/turtle.htm (USACE, 2003).

General dredging mitigation measures and those specifically involving the drag head operations (*italic*) that should be followed include:

- Environmental windows set outside of peak nesting season April to September when more turtles are in the area. This window is typically set to allow dredging between December and March.
- *Appropriate turtle deflectors on the drag head.*
- *Diligent, independent inspection of suction on the drag head to insure proper placement.*

- On-board management to minimize risks to turtles (pumps are turned off when the drag head is lifted from the bottom, and jet pumps are used to provide a mobile water curtain). These measures appear to be as effective if not more effective as turtle deflectors in reducing risks to turtles.
- Use of observers to visuallly monitor an exclusion zone surrounding the dredge activities and implement shut down procedures if a turtle is spotted within an established exclusion zone.
- Report potential turtle injury.
- Possible inclusion of pre-dredge turtle survey, trawling, and turtle relocation.

4.4.4 Sea Birds

Protected species present

Members of the family Laridae and frigatebirds are most likely to be present at the shoal sites. Although all birds are protected under the Migratory Bird Treaty Act, federally listed as threatened bird species that may occur near the shoal sites are the least tern and toseate tern. The least tern is likely to be present in all but the winter months (November-February) with peak numbers occurring from April – August. The roseate tern may occur in areas near the shoals as they migrate throughout Florida in spring and fall. Their breeding locations are confined to areas in extreme south Florida and in the Keys.

The royal tern, a year round Florida resident, visits coastal and pelagic zones and was observed during field events. The magnificent frigatebird, a coastal wading bird, is likely to occur at the shoal sites but less frequently than the Larids. The frigatebird was one of the most common birds seen during the field events. While frigatebirds may occasionally be seen year round they are more common during the summer.

Potential injuries to sea birds

The dredging process does not pose significant impacts to bird species likely to occur at the shoal sites outside temporary displacement from preferred habitat. The greatest risk to birds from dredging operations is physical injury within the scow during beach fill, and disruption to nests and nesting behavior on beaches. Terns and other birds will often fish in the scow as it is being filled. The influx of water and slurry bogs birds down until they are unable to fly out of the scow, which leads to drowning. It is possible that fishing birds, particularly plunge-diving terns could drown in the dredge scow.

Sea Bird Mitigation Measures

The following mitigation measures will reduce scow impacts to protected bird species:

- An environmental window that protects marine turtles will also help protect least terns in the area due to the overlap in seasonal concurrence.
- Observers placed for marine turtles should also monitor the scow for least terns or other terns if they are present in the area. Implement a shutdown protocol for least terns diving into the scow.
- Eliminate offloading food waste from the dredge during daylight to reduce attracting other birds that in turn can attract terns to the area.

4.4.5 Marine Mammals

Protected species present

Although twenty-nine species of marine mammal are listed as occurring in the Gulf of Mexico, many of those are found mainly beyond the 200m contour or are extralimital in range. Species found in the study areas are from the family *Delphinidae*, typically dolphin and small whale species common in the Gulf. All marine mammal species likely to occur at the shoals are protected under the Marine Mammal Protection Act as regulated by the National Marine Fisheries Service (NMFS). Three cetacean species were documented during the field surveys: (1) bottlenose dolphin, (2) Atlantic spotted dolphin and the (3) rough-toothed dolphin. These three and one additional species, the pantropical spotted dolphin are most likely to occur at the sites or in the nearby area. The pantropical spotted dolphin was added to this list due to its propensity to move in multi-species groups, particularly with rough-toothed dolphins that were present during the fall 2005 field event.

The sperm whale is the most common large whale and is a federally endangered species in the Gulf of Mexico. Although it is highly unlikely that a sperm whale will occur in the shoal areas, observers and operators should be aware this species resides in the Gulf and traverses multiple water depths; therefore, vigilant observation in the shoal areas is required during any dredging activity.

The North Atlantic right whale is considered a rare, extralimital species in the Gulf of Mexico. There have been documented sightings of right whales near the shoal sites, including a mother and calf that were tracked from Bradenton to Siesta Key to Venice remaining 2-5 miles offshore. The pair was in Corpus Christi, TX the previous month, which was also a rare occurrence. While the occurrence of right whales at the shoal sites would be highly unlikely based on the lack of frequent or regular sightings, they can occur in the area and marine mammal monitoring should be conducted during dredging operations.

Potential injuries to marine mammals (physical injury, turbidity, noise, food source)

<u>Dredge Operations</u>

Potential impacts to marine mammals likely to occur at the shoal sites are minimal. The speed of dredge operations does not pose a significant strike risk and direct physical injury to marine mammals from the drag head (for hopper dredging) is unlikely.

Noise impacts to marine mammals are a concern in ocean and coastal construction operations. Under the MMPA, NMFS determined that continuous sound levels above 120dB constitutes harassment of marine mammal species and can temporarily impair normal behavior patterns. There are no known marine mammal noise impact studies conducted on dredge operations and there is no indication that marine mammals would be injured or killed by the noise produced by dredging operations. A monitoring program and mitigation measures should be in place to avoid sudden onsets of potentially disturbing noise and to detect marine mammals in the area.

<u>Support Operations</u>

Tug, scow, and crew boat operations pose a risk to marine mammals. Those species most likely to occur at the shoal sites are dolphins, which are not at risk of extinction. The sperm whale and right whale need the most protection from vessel strikes. The slow movement (less than 10 knots) and low maneuverability of scows reduce their ability to avoid a strike. It is unlikely that either a sperm whale or a right whale would enter the study area, thus the likelihood of strike impacts are considered to be very low. All support operations working within 1 mile of shore and within intracoastal waters pose a significant strike risk for manatees.

Marine Mammal Mitigation Measures
A stringent observer program similar to that implemented under MMS NTL 2007-G02 *Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program* and strike avoidance measures as those required under MMS NTL 2007-G4 and NMFS (2006) *Vessel Strike Avoidance and Injured/Dead Protected Species Reporting* would provide optimal protection from mechanical injury and noise impacts to all marine mammals likely to occur near the shoals. These measures would supersede standard dredge monitoring methods typically implemented by USACOE. A noise monitoring program around the dredge operations would provide needed information on potential sound impacts to protected species.

Construction/dredge crew and vessel operator education on protected species should be a required integral part of any mitigation program. Crewmembers should be trained in basic observation techniques, identification techniques, and a thorough understanding of all federal and state laws and penalties concerning protected species.

4.5 Cumulative Impacts

The Council on Environmental Quality's (CEQ) regulations (40 CFR 1500-1508) implementing the procedural provisions of the National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. 4321 et seq.) define cumulative impacts as follows:

> *The impact on the environment, which results from the incremental impact of the action when added to other past, present, and reasonable foreseeable future actions regardless of what agency (federal or non- federal) undertakes such other actions (40 CFR 1508).*

To adequately address cumulative impacts, direct impacts from past and proposed dredging projects within a particular area should be identified. In addition to dredging projects, other projects and activities that potentially affect the physical and biological environments should be identified.

Potential cumulative impacts may result from multiple dredging operations within a borrow area. The affect on the physical environment may be a deep dredge cut and substantial lowering of the shoal profile. Additionally, dredging from immediately adjacent areas may not cause direct impacts such as entrainment but may cause turbidity and sediment deposition in an area previously dredged.

Potential cumulative impacts may result from borrow areas being sited in close proximity to one another. For example, T1 and T2 are located relatively close to one another such that dredging operations at either site may affect the other through turbidity and sediment deposition.

Cumulative impact assessments must also consider other projects in area or vicinity such as dredged material management sites, submarine infrastructure such as pipelines or cables, and fishing operations such as bottom trawlers or draggers, etc.

The anticipated dredge interval or beach nourishment requirements from T1 and/or T2 may span several years. Results from a recent dredge event on T1 and hypothetical dredge activities on T1/T2 and Siesta Shoals as analyzed in Cases 1-5 (Section 4.5.1) suggest there will be no short-term or long-term impacts on the nearshore for any of the study shoals. The effect of each simulated Case on the shoal depends on the degree of excavation. Cumulative impacts occur when the entire shoal is removed through a series of multiple cuts because the shoals on the west coast are not regenerated in modern geological conditions. Benthic recovery from dredging is expected to require approximately 2 years (Section 4.4.1.1), therefore significant potential cumulative impacts to the benthic community are considered unlikely. Due to the temporary nature of the dredging operations and the small likelihood of direct impacts, there are no expected cumulative impacts to the pelagic environment, including ichthyoplankton, fish, sea turtles, sea birds, and marine mammals.

4.5.1 Physical and Biological Resource Interactions

The response of biological resources to simulations of the borrow cuts (Cases 1-5) is examined to determine the potential impacts from the degree of dredging on each shoal and whether the outcomes of dredging negatively affect biological resources. Numerical modeling of dredge cuts varied from no borrow cut (Cases 1 and 4), to multiple cuts with removal of large volumes of material from each shoal (Cases 3 and 5). Prevention and/or mitigation measures for protected species (sea turtles, marine mammals, seabirds, and fish) likely to be present in the study areas and that may be impacted by dredging activity are provided in Section 4.4. In general, measures to protect listed species include modifications to schedules (*setting environmental windows*) and to operational procedures. Also evaluated are interactions of potential impacts to the benthic community from single, small magnitude dredge cuts vs. multiple dredge events that are planned until the entire shoal is altered.

Single Dredging Events

A single dredging event occurred in 2006 on T1 Shoal and removed 600,000 yd^3 of material decreasing elevation between 2 to 4 feet at the north end of the shoal. The benthic community is most directly impacted from any dredging. A single cut leaves intact a portion of the benthic habitat and thus some subpopulation of the shoal benthic inhabitants for re-population. Because no significant difference exists in taxa on or off the study shoals, the benthic community may be more or less uniform over a much larger geographical region. For these reasons, a single event cut is unlikely to result in a negative cumulative impact to the benthic community at large or the species dependent upon it. The length of time between dredging events may be considered to allow a successional community to develop.

Multiple and/or Repeated Dredging Events

Multiple dredging events can lead to removal of greater portions of a shoal and the likely alteration of the entire shoal elevation or morphology. This requires a slightly different analysis for impacts to benthic organisms. A review of existing literature reveals that the study sites and shoals on the west coast of Florida's continental shelf were formed in an earlier geologic time and in the modern offshore physical setting new shoals are not presently being formed. Thus, once a shoal is removed the scientific body of evidence does not predict regeneration of new shoals or reformation of these dredged shoals. The MMS may weigh the temporary loss of benthos area and deem it necessary to modify shoal design cuts, leave sections of shoals or selectively dredge some shoals and leave others intact as a measure to prevent loss of shoal habitat for benthic organisms.

4.5.2 Physical Environment Borrow Sites and Nearshore

Numerical modeling results indicate that neither the individual borrow cuts or larger multiple borrow cuts in this study area will have a significant influence on wave energy or sand transport rates in the nearshore zone and littoral environments landward of the shoal features. A detailed discussion of the model predictions for both the T1/T2 Shoal and Siesta Shoal regions is provided in Sections 4.3.1 and 4.3.2. Large borrow cuts that cover most of the foot print of the shoals simulated the removal of more than 9 million cubic yards of sand from the T1/T2 Shoal system and approximately 3 million cubic yards from the Siesta Shoal. Once these cuts were placed in the model bottom topography, two-year simulations were conducted using hind cast wave data at the model boundaries and measured water level and meteorological time series.

Results of wave predictions for the five model test cases (see Table 4-1) show that differences in the local wave pattern over the shoals can be expected between cases that included limited single borrow cut verses those cases that included the larger cuts covering most of the shoal. However examination of differences among the cases with respect to predicted wave height and direction shows that the influence of borrow cuts of any size were not detectible at the shoreline.

Since the shoal systems in this study are located in Federal waters more than 9 nautical miles from the nearest shoreline, refraction and shoaling effects over the irregular topography and decreasing depths of the inner continental shelf masked the influence of even the largest borrow cuts. This was particularly true for the Siesta Shoal, which is the smaller of the shoal features. Predicted sand transport rates and topographic evolution of the upper shoreface were nearly identical for all borrow cut cases. Thus, the influence of cumulative borrow cuts in sand shoal features of similar dimensions in Federal waters are likely to be small and not detectible at the shoreline.

Model results for the T1/T2 shoal feature located approximately 13 miles from the nearest shoreline predicted a very small but detectible influence at the shoreline. However, the influence in terms of predicted littoral transport rates were small compared to the expected natural variability of transport. Using the zone of influence identified from the results of the Case 3 (cumulative borrow cuts) test, three locations were identified within an 8 km section of shoreline where the predicted difference in littoral transport would reach the magnitude of natural variability (see Figure 4-24). A smaller zone of influence was also predicted for the single borrow cut already placed at the north end of the T1 Shoal (Case 2). However, the magnitude of the predicted influence is considered minimal and unlikely to have an important impact on the topographic evolution of the upper shoreface. This conclusion is supported by the comparison of predicted time series of depth change on the upper shoreface and lower shoreface. In all comparisons the trends of either accretion or erosion were identical before and after the cumulative borrow cuts. The predicted range of net difference in topographic evolution among all observations stations in the littoral zone was 1 to 3 cm for the maximum borrow cut of Case 3 and 1-2 cm for the existing borrow cut on the T1 Shoal modeled under Case 2.

Analysis of the morphologic evolution of the shoal features was not among of the goals of the model applications in this study. However, it is useful to review the model results as a guide to potential influence of large borrow cuts on the morphology of inner continental shelf linear shoal features. On the west Florida shelf there is little sand available for refilling borrows after cuts are made. Further, analysis of topographic data in the region indicates that the shelf topography beyond the shoreface has been stable since the origin of the shoals during the Holocene sea level transgression. The geologic setting and theories of shoal origin were reviewed under Section 2.3 of this report.

The expected topographic changes of the features for the pre- and post-borrow cut cases include re-working of the upper few cm of sediment by occasional storms. These storm-related impacts can be important in evaluating the potential for recovery of the benthic community after excavation. Figure 4-51 shows the predicted net topographic change over the T1/T2 Shoal after two years of simulation without a borrow cut placed in the model (Case 1, Table 4-1). Approximately 0.04 m or 4 cm of erosion was predicted over the highest elevations at the crest the T1 Shoal. No topographic changes were predicted for the T2 Shoal. Similar results were obtained after a two-year simulation with the existing borrow cut placed at the north end of T1 (Case 2; Figure 4-52).

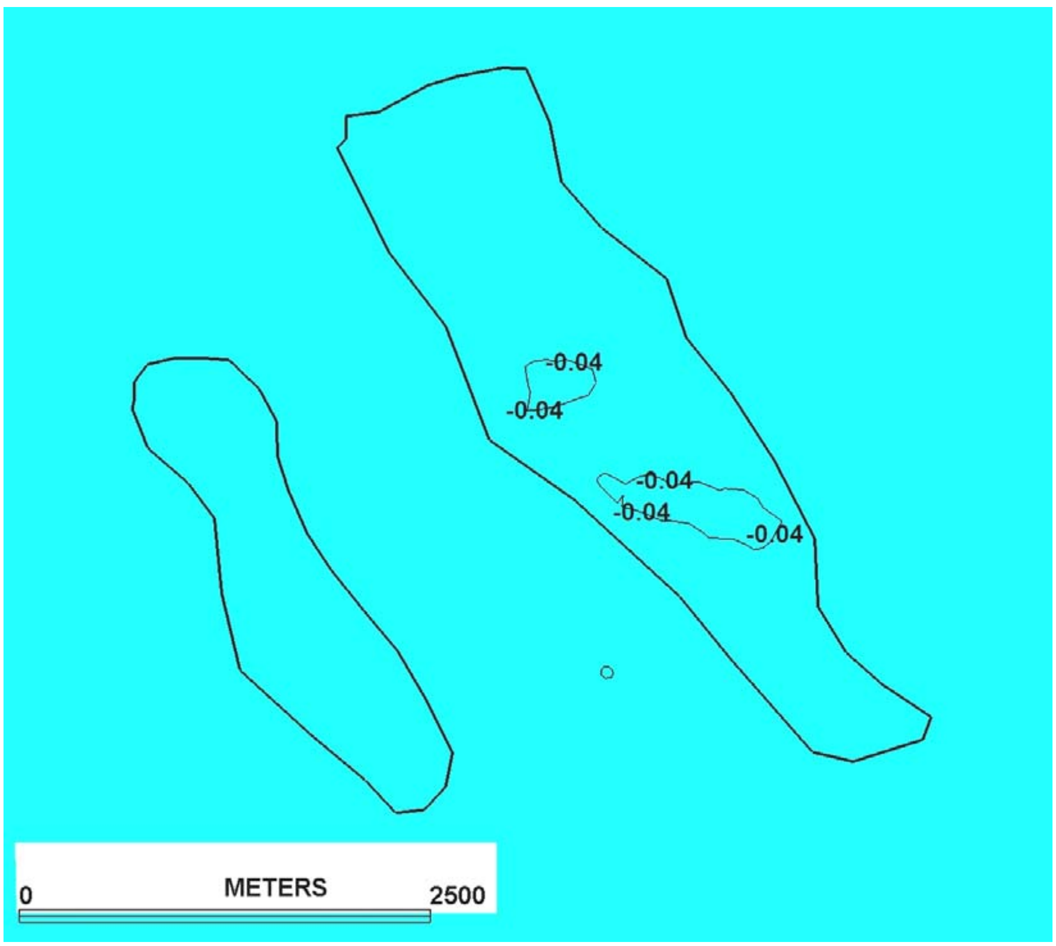


Figure 4-51. Predicted topographic change over the T1/T2 Shoal features after two years of model simulation under the without a borrow cut (Case 1, Table 4-1).

After placing the large borrow cut in the model as depicted in Figure 4-10, the results of the two-year simulation (Case 3, Table 4-1) show differences from the other T1/T2 model tests. In Case 3, topographic changes of 5 to 40 cm were concentrated along the boundary of both shoals (Figure 4-53). The location and magnitude of these changes indicate that modification of the T1/T1 Shoal features by the large

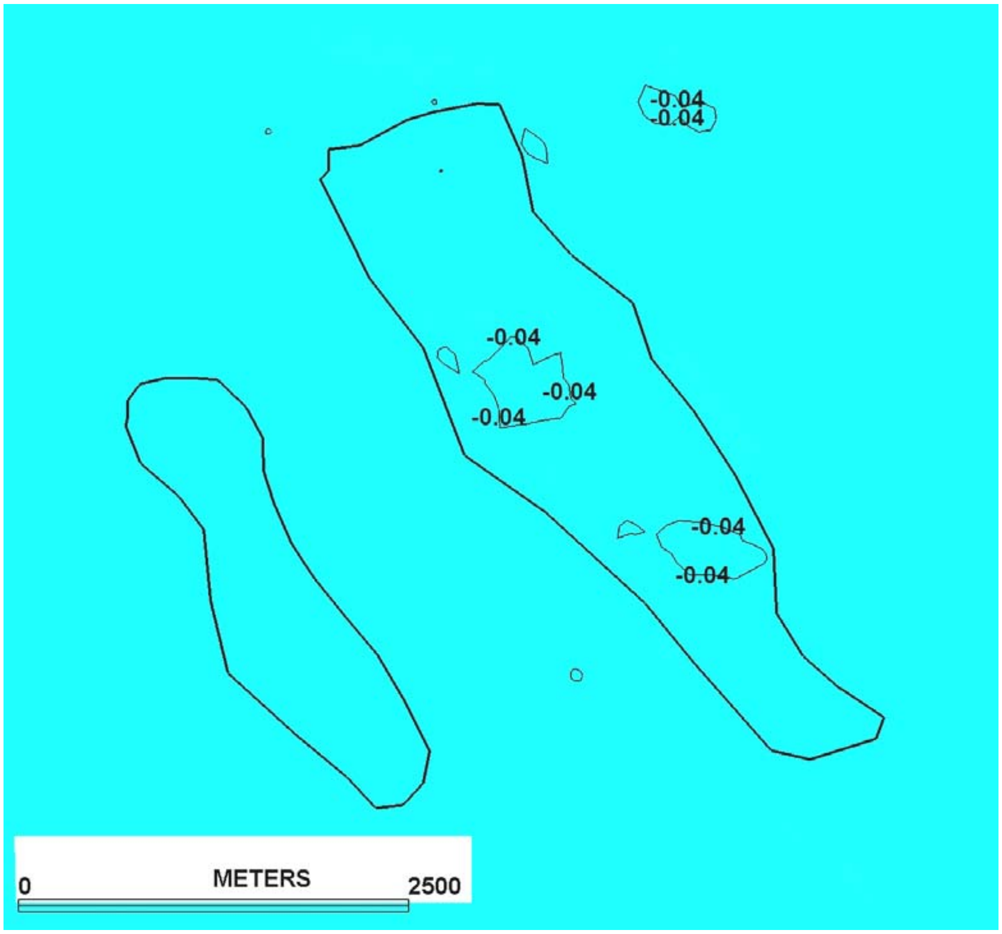


Figure 4-52. Predicted topographic change over the T1/T2 Shoal features after two years of model simulation with placement of the existing borrow cut at the north end of T1 (Case 2, Table 4-1).

borrow cuts created sharp topographic gradients that interacted with the wave field. Over longer time, periods some of the sharp topography created by borrow pits could be subject to smoothing. Thus there is a potential for some morphologic evolution of the edges of the borrow pits.

The results of model simulations over Siesta Shoal were similar to those of T1/T2, but less pronounced. Maximum predicted elevation changes were about 4 cm after the two year simulation without a borrow cut (Case 4, Table 4-1) as shown in Figure 4-54. After the large borrow cut was placed in Siesta Shoal the predicted magnitude of topographic changes over the simulation periods were similar, about 4 cm. However, the changes were shifted to the perimeter of the shoal where topographic gradients were sharper due to the presence of the borrow pit (Figure 4-55).

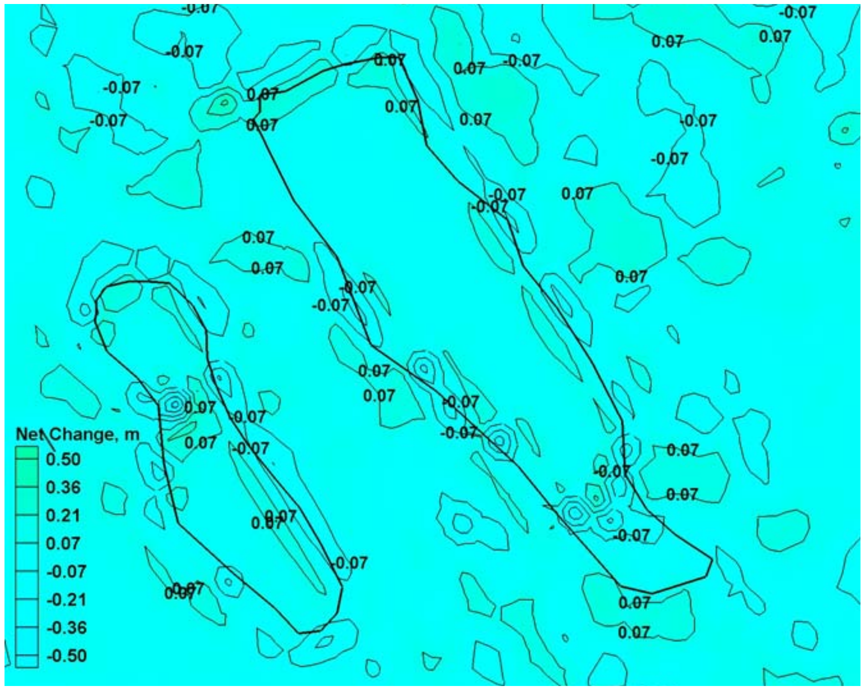


Figure 4-53. Predicted topographic change over the T1/T2 Shoal features after two years of model simulation with placement of the cumulative borrow cut over T1 and T2 (Case 3, Table 4-1).

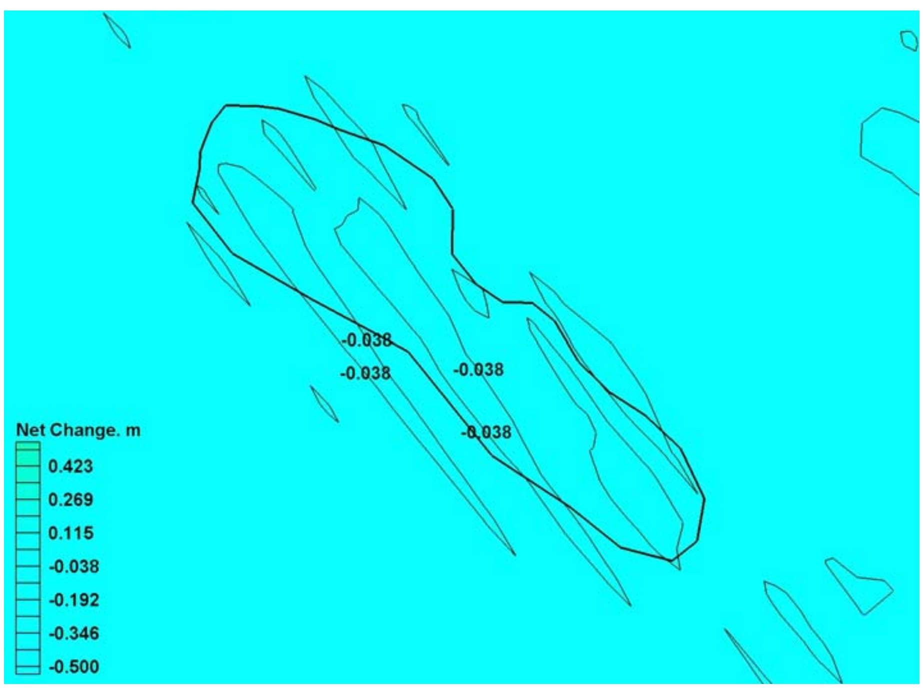


Figure 4-54. Predicted net topographic change over the Siesta Shoal features in the existing topography after two year of model simulation (Case 4, Table 4-1).

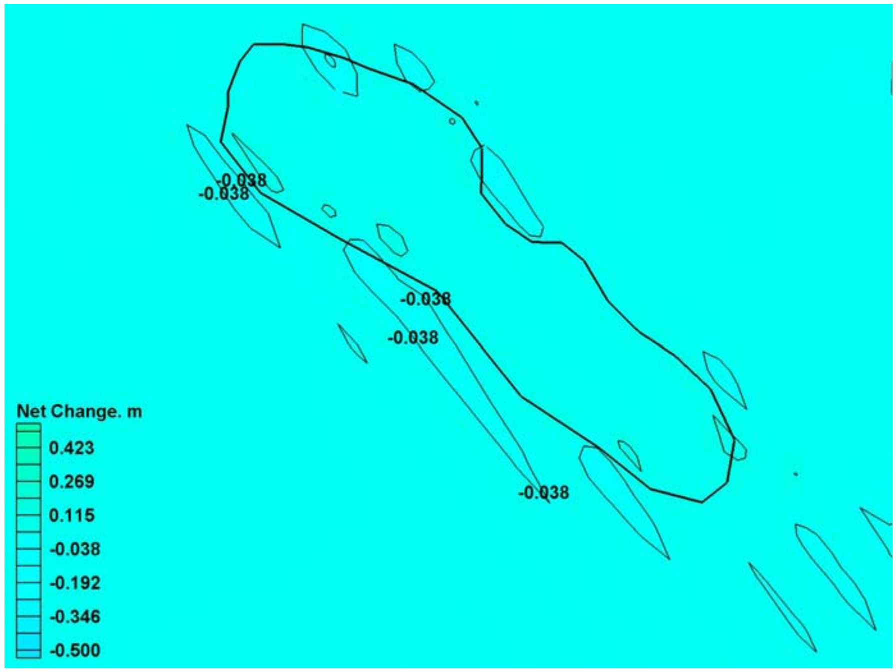


Figure 4-55. Predicted net topographic change over the Siesta Shoal features after the cumulative borrow cut (Case 5, Table 4-1).

The results of model simulations over Siesta Shoal were similar to those of T1/T2, but less pronounced. Maximum predicted elevation changes were about 4 cm after the two year simulation without a borrow cut (Case 4, Table 4-1) as shown in Figure 4-54. After the large borrow cut was placed in Siesta Shoal the predicted magnitude of topographic changes over the simulation periods were similar, about 4 cm. However, the changes were shifted to the perimeter of the shoal where topographic gradients were sharper due to the presence of the borrow pit (Case 5, Figure 4-55).

4.5.3 Potential Cumulative Impacts to Biological Resources

The likely presence of federally protected species in the study areas, as well as, in the Gulf of Mexico has been well documented in species accounts from literature reviews. Considering the number of listed species and the population counts of these species together with the temporal nature of dredging operations, it is highly unlikely that cumulative impacts to protected species will occur. Especially if the MMS follows the protection, measures and appropriately schedules dredge events as recommended in this report.

The most recent dredging event in the study area was the 2006 dredging of 600,000 cubic yards from T1 Shoal, which was analyzed as a past event. Hypothetical excavations on T1/T2 (Case 3) and on Siesta Shoal (Case 5) as described in Section 4.5.1 were considered in assessing future cumulative impacts.

Benthos

The abundances, species numbers, and diversity of the benthic community in dredged area may recover to background levels relatively rapidly; however, species composition may take a longer period of time

(Section 3.3.3). In terms of cumulative impacts, if dredging occurs multiple times in the same area over a relatively short period, e.g., 2 – 3 years, recovery of the impacted area will be prolonged. If the disturbed area is not given sufficient time to adequately recover from an initial dredging event, it is anticipated that the recovery time will be prolonged. Additionally, because the benthic community composition is closely tied to sediment composition, progressively deeper dredge cuts may expose sediments with different grain size and other physical characteristics than the pre-dredged conditions. Multiple dredge cuts in an area may also result in deeper trench or even pit-like features on the bottom, which would result in changes in hydrodynamic conditions at the bottom of such features such that recovery rates may extend beyond the 1 – 2 years predicted based on the literature. However, because the benthic assemblages on the sand shoals examined were similar to the assemblages in the adjacent areas off the shoals and the spatial extent of the dredged area is small compared to the broad area of the west Florida shelf, it is expected that there would be a negligible impact on the ecosystem. Even though site-specific cumulative impacts may be detectable, the high densities and fecundity of the benthic populations in the area together with the relatively small area of impact would preclude significant long-term effects on the benthic populations even from a cumulative impact perspective.

Slow-moving and burrowing epibiota inhabiting the study area such as sand dollars, brittle stars, and decapods, would most likely experience a reduction in density due to sediment removal and entrainment in the suction dredge during each dredge event. However, it is anticipated that these motile populations would recover relatively rapidly and, if the topography of the dredged area is not dramatically different than the adjacent areas i.e., not "pit-like", there would be no significant cumulative impact. The motile epifauna generally are migratory and are not restricted to the borrow areas.

Fishes

Cumulative impacts to the local fish fauna are also expected to be minimal. Dredging operations will most adversely affect soft-bottom demersal fishes through entrainment or removal of their invertebrate forage base. However, given the planktonic dispersal strategies of most OCS fishes and the relatively high adult mobility of even small fish taxa, recolonization will occur after each dredge cut. This recolonization should proceed rapidly because the species assemblage outside borrow sites appears similar, offering a proximate source of recruits. Nonetheless, community composition within a given dredge cut may not rapidly return to its pre-dredge state, especially if changes to sediment composition and the benthic invertebrate assemblage persist for several years. Any such delay would have negligible ecosystem-level consequences since most fish species found within these dredge sites are common and widespread along the west Florida shelf. Cumulative impacts to reef fish taxa (a legitimate issue in many areas due to mechanical damage or siltation of exposed hardbottom) is of minor concern locally since no hardbottom is present within the proposed borrow areas. Impacts to pelagic fish species are also negligible given their high mobility and limited reliance on substrate type and benthic invertebrate prey.

Marine Mammals

Dolphin species are the most likely marine mammal that will be present in the study areas. Routine activities associated with dredging the OCS material on the study sites are not expected to have short or long-term adverse effects on the size and productivity of any marine mammal species or population endemic to the Gulf of Mexico. Recommendations for avoidance of marine mammals during dredging are provided in Section 4.4.

Sea Turtles

Although sea turtles are most likely to incur potential lethal harm from dredging activities, take incidences have decreased with implementation of combined protective actions. The numbers of harmful incidences that may occur are unlikely to have significant adverse effects on the size and recovery of any sea turtle species or population native to the Gulf of Mexico. Most routine OCS activities are expected to have sublethal effects. Although lethal effects can occur and are more likely to occur from entrainment during dredging, recommendations for preventing interactions between dredge operations and sea turtles are discussed in Sections 4.4 and 5.

Sea Birds

Impacts to sea birds and sea bird habitat are expected to be none to minor in scope and short term in duration. The effects of routine dredging activities at the study sites on sea birds may result from the intake of discarded debris. Sea birds observed in the Gulf are dominantly trans-migrants, shorebirds, wading birds, and waterfowl that may occupy the study area briefly if ever or use the dredgers and boasts for temporary resting places. They may be attracted to trash discarded on dredge vessels or thrown overboard. The best avoidance measure is to manage debris as discussed in Section 4.4.

5.0 DISCUSSION OF POLICIES, REGULATORY REQUIREMENTS, AND MEASURES TO OFFSET POTENTIAL ENVIRONMENTAL IMPACTS

5.1 Policies and Regulatory Requirements

This section distinguishes regulations and policies under Federal or Florida jurisdiction and describes pertinent polices that were considered for potential environmental impacts from dredging activities to the physical resources and the biological communities in the vicinity of and on the three OCS study areas. Although dredge and fill activities in the coastal zone are regulated by the State of Florida, the coastal zone is defined as that area of land and water from the territorial limits seaward to the most inland extent of marine influences, potential erosion impacts to the shoreline from dredging activities on the study areas were analyzed from results of numerical modeling. The FDEP Joint Coastal Permit Application is the vehicle for implementation of state regulations governing the zone from the MHWL and seaward. Aside from potential shoreline erosion analysis, additional environmental impacts from dredge and fill activities that occur onshore and in state coastal waters are outside the scope of this study.

Several Federal Acts provide direction and authorization to agencies and organizations to further the protection of natural and economic resources. References to these Acts are mentioned throughout this report with regard to impacts to protected species and their habitat. If a potential impact was considered likely and under the purview of a Federal policy, the recommendations for remedy were prioritized in order of avoidance, minimization, and/or mitigation. Acts relevant to future dredging projects in the study areas are the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), the Magnuson-Stevens Fishery Conservation and Management Act (MSA), the Migratory Bird Treaty Act (MBTA), the Coastal Zone Management Act (CZMA), and the Outer Continental Shelf Lands Act (OCSLA).

5.1.1 National Environmental Policy Act (NEPA)

The National Environmental Policy Act (NEPA) United States Code Citation: 42 U.S.C. § 4321-4347 is the basic national charter for protection of the environment. The Act is a national policy to "encourage productive and enjoyable harmony between man and the environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; and to enrich the understanding of the ecological systems and natural resources important to the Nation" (42 U.S.C. 4321). The profound impacts of human activities on the interrelationships of the natural environment" are recognized (e.g., urbanization, population growth, industrial expansion, resource exploitation). The Act calls for the Federal Government in cooperation with state and local governments and other public and private organizations to use all practicable means and measures to fulfill the policy.

Federal agencies are responsible for improving and coordinating program plans and actions to meet policy goals. Agencies must use a systematic, interdisciplinary approach to ensure the integrated use of science and environmental design to plan and conduct decision making. Unquantifiable environmental amenities and values may be considered in decision making along with economic and technical considerations (Section 102(2)(A)) (42 U.S.C. 4332 (2)(A)).

The method for implementing NEPA is a multi-step decision process that begins with an assessment of the regulated resource and the potential impacts attached to it known as an environmental impact statement (EIS). This study provides the in-depth, area-wide, interdisciplinary scientific evaluation of the T1/T2 shoal system and the Siesta Shoal borrow area required for preparation of an EIS assessment and subsequent environmental assessments (EA). The MMS representatives in consultation with other agencies must decide if an EA is warranted for the extraction of offshore sand resources, in this case for non fee and noncompetitive lease agreement(s) with counties in southwest Florida or the State of Florida for the purpose of beach re-nourishment. The MMS may use sections of this report or it may be adopted in whole to base decisions on the EIS and EA analysis.

In addition, the physical similarities of the T1/T2 Shoal system and Siesta Shoal with other sand shoals in Federal waters offshore of Anclote Key north of Tampa Bay to offshore of Marco Island to the south may be considered tierable for future EIS and EA decisions. Shoals studied in this report are examples of geological features that share a common geological history, material composition, and minimum distance from the coast. Potential impacts to the shoreline from dredging on unstudied shoal features in Federal waters are likely to produce results similar to those produced from the numerical model case simulations applied to shoals in this study, which tested extracting different volumes of material under extreme storm conditions.

Potential biological impacts in dredging shoals outside the study sites from north of Tampa Bay to the Florida Panhandle may be considered tierable for certain protected species of the biological communities. The listed species of sea turtles and marine mammals researched for the present study are found consistently from Collier County north on Florida's west coast to the Panhandle. The composition of documented offshore species listed as endangered and threatened changes south of Collier County.

5.1.2 Endangered Species Act (ESA)

The MMS will participate in the Endangered Species consultation in preparation of negotiated lease agreements for the shoals studied herein and possibly for shoals offshore of Florida's west coast north of the study areas. The Endangered Species Act (ESA) United States Code Citation: 16 U.S.C. 1531 et seq., provides a means to conserve the ecosystems upon which endangered species and threatened species depend and a program for the conservation of such endangered species and threatened species (16 U.S.C. 1531). It establishes a policy that all Federal departments and agencies use their authorities to further the purposes of this Act (16 U.S.C. 1531 and 1536).

Section 7 (16 U.S.C. 1536) directs all Federal departments and agencies to consult on any actions authorized, funded, or carried out by them to prevent jeopardy to the continued existence of any endangered or threatened species, or cause the destruction or adverse modification of designated critical habitat of such species unless an exception has been granted by the Endangered Species Committee (16 U.S.C.1536 (a)(2)). There are no designated critical habitats for listed species in the three study areas. Results of the study do not find dredging of any or all of the studied shoals to jeopardize the continued existence of any endangered or threatened species.

Protected species are likely to be present in the study areas. This requires consultation between the MMS and USFWS/NMFS for a biological assessment and a biological opinion stipulating measures in the lease agreement for avoidance, minimization and mitigation in accordance with Section 9 (16 U.S.C. 1538). Prohibited acts identified in Section 9 relate to the "take" of endangered species by all persons, including all Federal, state and local governments except as specified under the provisions for exemptions (16

U.S.C. 1539). The term "take" is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct (16 U.S.C. 1532(18)). Provisions for civil penalties, criminal violations, enforcement, and citizen suits are found at 16 U.S.C. 1540.

5.1.3 Marine Mammal Protection Act (MMPA)

This Marine Mammal Protection Act (MMPA), United States Code Citation: 16 U.S.C. § 1361 et seq, 1401-1407, 1538, 4107 establishes a moratorium on the taking and importation of marine mammals and marine mammal products, with exceptions for scientific research, allowable incidental taking, exemptions for subsistence activities by Alaskan natives and hardship exemptions (16 U.S.C. 1371). Marine mammals (dolphins) were observed in the study areas and are very likely to be present during dredging. It is possible that sperm whales will also transit the study areas. Although it is highly improbable that the dredging activity will cause a taking, the implementation of avoidance actions and measures is recommended to prevent its occurrence. During the consultation process with USFWS and NMFS, the MMS will decide the merits of recommended deterrents to avoid harm to marine mammals that may transit through the offshore sites during dredging or that may encounter dredge vessels near the study sites.

5.1.4 Migratory Bird Treaty Act (MBTA)

The Migratory Bird Treaty Act (MBTA), United States Code Citation: 16 U.S.C. § 703-708,709a-712 provides policy to protect migratory bird species native to North America and exemptions for permitted activities. It is unlawful at any time, by any means or in any manner to or attempt to pursue, hunt, take, capture, kill, or possess, offer for sale, sell, offer to barter, barter, offer to purchase, purchase, deliver for shipment, ship, export, import, cause to be shipped, exported, or imported, deliver for transportation, transport or cause to be transported, carry or cause to be carried, or receive for shipment, transportation, carriage, or export, any migratory bird, any part, nest, or eggs of any such bird, or any product, whether or not manufactured, which consists, or is composed in whole or part, of any such bird or any part, nest, or egg thereof, included in the terms of the conventions between the U.S. and Great Britain, the United Mexican States, the Government of Japan, and the former Union of Soviet Socialist Republics. The list of birds protected under the MBTA was compared with seabirds observed during previous studies in the Gulf and sea birds observed during our field studies of 2005 and 2006. The result was a list of species likely to be present in the vicinity of the study areas which are discussed in Sections 2 and 3 of this report. Although it is unlikely that the presence of birds during dredging operations in and near the study areas will lead to impacts, recommendations for actions to avoid potential impacts are provided in Section 4.

5.1.5 Magnuson-Stevens Fishery Conservation and Management Act (MSA)

The Magnuson-Stevens Fishery Conservation and Management Act (MSA), United States Code Citation, 16 U.S.C. § 1801 et seq. as amended by the Sustainable Fisheries Act of 1996 (Public Law 104-267) and reauthorized in 2006 (P.L. 109-479), provides for the conservation and management of fisheries, and for other purposes. The 1996 amendment of the MSA Act requires description and identification of "essential fish habitat" (EFH) in each fishery management plan (FMP). EFH is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity". *Waters* include aquatic areas and their associated physical, chemical, and biological properties. *Substrate* includes sediment underlying the waters. *Necessary* means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem. *Spawning, breeding, feeding, or growth to maturity* covers all habitat types utilized by a species throughout its entire life cycle.

Only species managed under a Federal fishery management plan are covered. FMPs are established by the eight regional fishery management councils. The MSA requires all Federal agencies to consult with the NMFS prior to actions, or proposed actions, which are permitted, funded, or undertaken by the agency that may adversely affect EFH. Adversely affect means any impact that reduces the quality and/or quantity of EFH. Adverse affects may include direct (e.g., contamination, physical disruption), indirect (e.g., loss of prey), site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions.

Between 1979 and 1986, the Gulf of Mexico Fishery Management Council (GMFMC) developed FMPs for reef fish (43 species), red drum (1 species), coastal pelagics (3 species), stone crab (2 species), shrimp (4 species), spiny lobster (2 species), and corals, each of which has been amended several times. Coastal migratory pelagics and spiny lobster were developed jointly with the South Atlantic Fishery Management Council (SAFMC) because stocks of these managed species overlap both regions. Combined, 55 fish and invertebrate species (excluding corals) are included in Gulf of Mexico FMPs. In addition, 44 species of Atlantic sharks, tuna, swordfish, and billfish are managed under the highly migratory pelagics FMP developed by the NMFS Highly Migratory Species Management Unit, several species of which are also found in the Gulf of Mexico. A list of individual fish and invertebrate species in which EFH boundaries overlap or are in the vicinity of proposed sand borrow sites are provided in Table 5.1.

Regional fishery management councils also have the authority to designate Habitat Areas of Particular Concern (HAPC) to focus conservation efforts on areas of EFH which play a particularly important role in the life history of federally managed fishery species, are especially vulnerable to degradation, are under stress, or are rare. In the Gulf of Mexico, HAPC consists of discrete high relief hard-bottom areas (e.g., Florida Middle Grounds, Madison-Swanson Marine Reserve, Tortugas Ecological Reserves, Flower Garden Banks) which harbor high densities of reef fishes, and are thought to serve as critical spawning and nursery areas. No HAPC is located in the immediate vicinity of proposed sand borrow sites.

An important consideration when exploiting OCS sand resources is the mandate to conserve and manage both marine and diadromous fishery resources found in shelf waters of the U.S. Exclusive Economic Zones (EEZ). Based on information obtained during the literature review as well as results of field sampling events of 2005 and 2006, there is no indication of adverse impacts to protected fish species. Nonetheless, some of the revisions and additions of the MSA 2006 reauthorization may change the MMS approach to lease agreements or consultation negotiations with NMFS. These MSA changes include: (1) the addition of ecosystem research on a regional scale; (2) the implementation of measures to streamline the NEPA procedures; and (3) the designation of zones by FMPs to protect deep sea corals and inclusion of conservation measures for non-target species (MSA Implementation Overview, 2007). The 2006 policy change also includes improvements to the recreational statistical methods of catch data to improve scientific analysis of fish harvesting. These adaptations to improve research could improve data acquisition for the MMS planning and leasing of OCS sand and gravel. Directives to streamline NEPA procedures may also benefit the objectives of the MMS.

Table 5-1. Species managed under federal fishery management plans (FMPs) in which potential essential fish habitat (EFH) overlaps or is in close proximity to proposed sand borrow sites.
* indicates FMP jointly managed with the SAFMC.

Reef Fish FMP		Red Drum FMP	
Balistes capriscus	Gray triggerfish	*Sciaenops ocellatus*	Red drum
Caulolatilus chrysops	Goldface tilefish		
Caulolatilus cyanops	Blackline tilefish	**Coastal Migratory Pelagics FMP***	
Caulolatilus intermedius	Anchor tilefish	*Rachycentron canadum*	Cobia
Caulolatilus microps	Blueline tilefish	*Scomberomorus cavalla*	King mackerel
Diplectrum bivittatum	Dwarf sand perch	*Scomberomorus maculatus*	Spanish mackerel
Diplectrum formosum	Sand perch		
Epinephelus adscensionis	Rock hind	**Stone Crab FMP**	
Epinephelus drummondhayi	Speckled hind	*Menippe mercenaria*	Stone Crab
Epinephelus flavolimbatus	Yellowedge grouper		
Epinephelus guttatus	Red hind	**Shrimp FMP**	
Epinephelus inermis	Marbled grouper	*Farfantepenaeus aztecus*	Brown shrimp
Epinephelus itajara	Goliath grouper	*Farfantepenaeus duorarum*	Pink shrimp
Epinephelus morio	Red grouper	*Litopenaeus setiferus*	White shrimp
Epinephelus mystacinus	Misty grouper	*Pleoticus robustus*	Royal red shrimp
Epinephelus nigritus	Warsaw grouper		
Epinephelus niveatus	Snowy grouper	**Spiny Lobster FMP***	
Epinephelus striatus	Nassau grouper	*Panulirus argus*	Spiny lobster
Etelis oculatus	Queen snapper	*Scyllarides nodife*	Slipper lobster
Lachnolaimus maximus	Hogfish		
Lopholatilus chamaeleonticeps	(Golden) Tilefish	**Highly Migratory Species FMP**	
Lutjanus analis	Mutton snapper	*Carcharhinus acronotus*	Blacknose shark
Lutjanus apodus	Schoolmaster	*Carcharhinus brevipinna*	Spinner shark
Lutjanus buccanella	Blackfin snapper	*Carcharhinus leucas*	Bull shark
Lutjanus campechanus	Red snapper	*Carcharhinus limbatus*	Blacktip shark
Lutjanus cyanopterus	Cubera snapper	*Carcharhinus plumbeus*	Sandbar shark
Lutjanus griseus	Gray snapper	*Galeocerdo cuvier*	Tiger shark
Lutjanus jocu	Dog snapper	*Ginglymostoma cirratum*	Nurse shark
Lutjanus mahogoni	Mahogany snapper	*Negaprion brevirostris*	Lemon shark
Lutjanus synagris	Lane snapper	*Sphyrna mokarran*	Great hammerhead
Lutjanus vivanus	Silk snapper	*Sphyrna tiburo*	Bonnethead
Mycteroperca bonaci	Black grouper	*Thunnus thynnus*	Bluefin tuna
Mycteroperca interstitialis	Yellowmouth grouper		
Mycteroperca microlepis	Gag		
Mycteroperca phenax	Scamp		
Mycteroperca venenosa	Yellowfin grouper		
Ocyurus chrysurus	Yellowtail snapper		
Pristipomoides aquilonaris	Wenchman		
Rhomboplites aurorubens	Vermilion snapper		
Seriola dumerili	Greater amberjack		
Seriola fasciata	Lesser amberjack		
Seriola rivoliana	Almaco jack		
Seriola zonata	Banded rudderfish		

5.1.6 Coastal Zone Management Act (CZMA) and Outer Continental Shelf Lands Act (OCSLA)

The Coastal Zone Management Act (CZMA), United States Code Citation: 16 U.S.C. § 1451-1464, provides for state review of Outer Continental Shelf lease sales, exploration, and development. The Act requires consistency of Federal activities with federally approved coastal zone management plans. The "outer continental shelf" (OCS) is a jurisdictional term used to describe those submerged lands that lie seaward of state water boundaries (9 nautical miles off Florida’s west coast and 3 nautical miles off the east coast). The MMS is the Federal government agency that manages the natural resources on the OCS, while states manage the resources directly off their coasts. The Outer Continental Shelf Lands Act (OCSLA), 1953 (67 Stat. 462) as amended (43 U.S.C. 1331 et seq. (1988)), is the principal federal law governing mineral activities in federal waters. It was written to guide decisions concerning the exploration for the development of oil, natural gas, and other mineral resources on the OCS. Under the OCSLA, the MMS manages the orderly development of OCS actions and coordinates with states to protect human, marine, and coastal resources. Sand and gravel resource extraction under the OCS are authorized on a noncompetitive and non fee basis to government entities.

The State of Florida clearing house for federal and state interaction is supervised by the Secretary of FDEP who serves as the Governor’s contact for OCSLA and CZMA activities. Florida has an approved coastal zone management plan, which is administered through the FDEP Coastal Management Program in the Office of Intergovernmental Programs (OIP). Under the direction of the OIP Administrator, the State coordinates the reviews of OCSLA documents, NEPA documents, CZMA reviews, proposed laws, rules, information requests, and other materials associated with offshore activities. The OIP staff provides technical analyses, recommendations, and expertise, as well as, communicates state policy and develops state responses on OCS issues (FDEP, 2007).

The Florida OIP is also the contact point for the U.S. Environmental Protection Agency, Gulf of Mexico Program (GMP). The GMP is a network of state and federal agencies; citizens; businesses and industry; non-profit organizations; and others who are committed to managing and protecting the resources of the Gulf of Mexico. The purpose of the GMP is to provide financial and technical assistance to Gulf States and communities that are facing increasing demands on coastal resources. The GMP is composed of the Policy Review Board, the Management Committee, the Gulf of Mexico Citizens Advisory Council, the Gulf of Mexico Business Council and four Focus Teams comprised of technical and scientific professionals. The Focus Teams cover Habitat, Non-indigenous Species, Public Health and Nutrient Enrichment.

The MMS transmits planning activity for OCS resource use to the OIP Administrator as is called for in Section 307 (16 U.S.C. 1456(c)(1)(A)). This includes Federal agencies that propose activities or development projects, whether within or outside of the coastal zone, that are reasonably likely to affect any land or water use or natural resource of the coastal zone. Non-Federal projects requiring a Federal permit for an activity in or outside of the coastal zone, affecting any land or water use or natural resource of the coastal zone of the state, must provide certification to the permitting agency that the proposed activities comply with the enforceable policies of the state approved programs. No license or permit shall be granted by a Federal agency until the state has concurred with the applicant’s certification or until the state has waived its right to do so (16 U.S.C. 1456 (c)(3)(A)).

5.2 Recommendations for Mitigating Potential Impacts

Recommendations for mitigating potential impacts to protected species and physical features include setting the environmental window, using preferred dredge equipment, modifing operational procedures, and timing the dredge cuts to minimize impacts on benthic recolonization cycles. A number of activities are suggested for achieving beach renourishment projects and protecting listed species and their habitat. Protection of the most prevalent listed species, sea turtles, centers on setting dredging events that avoid nesting season. Scheduling dredge event windows to avoid sea turtle nesting season benefits other species as well. The environmental window for minimizing sea turtle takes is from December 1st to March 31st before and after the peak period of sea turtle nesting season from April to October. Many of the economically important fish listed in Appendix A spawn in the same environmental window. Tern species are also present in greater numbers as tern and sea turtle nesting seasons overlap.

Operational procedures for limiting harm to sea turtles, seabirds, and marine mammals include specifying the type of dredge equipment (hopper dredge with turtle deflectors), using on-site observers for all species, and controlling speed to avoid mammal collisions. Pre-dredge turtle surveys are recommended to identify and relocate sea turtles as a means of avoiding and mitigating take incidences.

Preserving physical features may be considered when the proposed design cuts in lease agreements would severely alter all shoals in a study area or remove them entirely. In this study, the T1 and T2 shoals are close to each other and the proposed cuts in the lease agreement between the MMS and Collier County does not approach elimination of both shoals (MMS, 2005). Future agreements may consider limiting the number of borrow cuts to leave sections of one shoal or portions of both T1 and T2 shoals unaltered. The third shoal, Siesta is relatively isolated from other shoal features and the design parameters used in the lease agreement may consider cut designs to avoid total alteration. If MMS deems no benefit is derived by alternate design cuts or by leaving a portion of the shoal intact; it may want to consider a window that frames a recovery period for the benthic community. The timing of cuts may be interrupted by 1-2 years or the estimated range of recovery time for benthic organisms. Lease agreements are for a one-year period. The period of recovery may naturally occur between new lease agreements if leases are in effect during alternate years.

6.0 CONCLUSIONS

This study characterizes the physical and biological environments of three offshore sand sources and identifies the potential environmental impacts from dredging on the borrow sites and impacts that may result on the nearshore beaches of Florida's west coast. Information from literature research and field studies were collected and analyzed to assist in developing criteria for future negotiated lease agreements, NEPA documents (Environmental Assessments and Environmental Impact Statements), and other regulatory permits as required for use of Federal sand and gravel deposits off the west Florida coast.

6.1 Characterization of Physical Environments Offshore and Nearshore

A review of the historic geologic evolution of west coast continental shelf features was undertaken to characterize the dynamics of formation and morphological transformation that occur to shoals. This comprehensive qualitative understanding of shoal dynamics was further examined through numerical modeling of physical processes over the shoals and at the shoreline to determine if over time the local wave field and hence patterns of accretion/erosion at the shoreline may be affected by excavation of borrow areas. Predicted sand transport rates in the littoral zone were also compared with and without the borrow cuts placed in the model domains to determine if excavation of the shoals is likely to have influence at the shoreline.

6.2 Numerical Model Predictions of Offshore Borrow Sites

A review of the existing physical data indicates that the west Florida inner continental shelf is characterized by wind-forced circulation at depths shallower than 50m. As described in Section 2.4 strong seasonal variations of inner shelf circulation, sea level, and the occurrence of storms can be expected. The model simulations were setup to include these effects, and particularly to include the higher energy conditions associated with both tropical end extra-tropical storms.

Previous work by the U.S. Geologic Survey (USGS) on the development and evolution of the inner shelf sand resources off west Florida summarized by Locker et al. (2003) provided guidance on selection of the representative shoal features included in this study. The project area from Sarasota to Sanibel Island is part of the Gulf Barrier Chain and Lagoon section of Florida's west coast where modern barrier islands developed from sediment sources derived from erosion of earlier shallow marine quartz-rich deposits. In the MMS study areas the USGS studies emphasize the importance of antecedent topographic control and sediment supply for shoal development. The west Florida shoal features developed in a sand starved environment relative to the more sediment abundant environment of the east central and northeast Florida inner continental shelf.

From Siesta Key to Sanibel Island inner shelf topographic gradients are set by the pre-Holocene carbonate surface as described in Section 2.3. Between the unconsolidated sand and gravel of shoal features extensive occurrence of carbonate hardbottom exposures can be expected. South of Tampa Bay sand ridges of low topographic relief are likely to have formed in the littoral environment from retreating barrier systems or by tide-generated currents that reworked older unconsolidated sands. Rising sea level over the past few thousand years has converted the west Florida shoals to relict features subject to only surficial reworking by storms.

Shoal features, in their present form, within Federal waters have a maximum overburden of approximately 3m of clean sand and carbonate-rich gravels that can be excavated for beach nourishment. Thus, the borrow cuts must be designed with this restriction. The model tests performed in this study were based on single cuts having a maximum excavation depth of about 2 m and on larger cuts of similar depth, but larger areas to simulate repeated borrowing from the a single shoal. The crest elevations of the T1/T2 shoal system reach depths of approximately -11m MSL and thus longer period waves associated with more severe conditions were predicted to be influenced by the presence of this shoal system situated 12 miles offshore. This influence included some increases of wave height to the east and north of the shoal depending on wave direction. Model results indicated some influence for all cases tested for T1/T2. However, the detectable changes in wave height were limited to very long period waves able to interact with the bottom topography. Furthermore, detectible changes in wave height diminished inshore of T1/T2 where irregular topography and decreasing depth overwhelmed the influence of the borrow areas.

Sand transport predictions in the littoral zone, dominated by breaking waves, indicated very small but detectible differences between model tests with and without borrow cuts in the T1/T2 Shoal system. The influence at the shoreline was slightly larger for the cumulative borrow cut that simulated removal of more than 9 million cubic yards of sand from the T1/T2 combination. However, when the predicted net sand transport is compared to the natural variability of transport along the shoreline, the predicted differences were mostly well below the expected variability indicating minimal potential for impact. This conclusion is supported by calculation of topographic evolution of the upper shoreface adjacent to the shoreline. Here, net predicted topographic change among the model test cases varied by about 1 to 3 cm or about 0.03 to 0.2 ft.

Model results were similar, but less pronounced, for the Siesta Shoal located about 15 miles offshore of Siesta Key in Sarasota County, Florida. The crest of Siesta Shoal reaches an elevation of about -13m compared to -11 m for T1/T2. Thus, topographic influence on wave and wave refraction is less frequent compared T1/T2. Prediction of transport and topographic evolution in the littoral zone onshore of Siesta Shoal is virtually identical between the two model test cases that were performed.

Model test cases that included large volume cuts in the shoals to simulate cumulative impacts of multiple sand recovery projects did not yield any further significant potential for impact at the shoreline. However, the borrow pits in the shoals that remain after excavation are likely to produce irregular topography and relatively steep side slopes that will be smoothed over several years. The model predictions over cumulative cuts predicted topographic changes that were concentrated at the perimeter of the borrow areas. Thus, model results indicate a potential for topographic smoothing of at least the perimeter of the borrow excavation pits over a period of a few years.

6.3 Benthic

Based on the results of the field surveys and examination of the literature on benthic recovery rates from disturbances, it is anticipated that abundances, species numbers, and diversity in dredged area may reach background levels relatively rapidly; however, species composition may take a longer period of time. Dredging the sand shoals examined during this project will result in an immediate decrease in the abundance, diversity, and biomass of benthic organisms within the dredged footprint. Because the benthic assemblages on the sand shoals examined were similar to the assemblages in the adjacent areas off the shoals and the spatial extent of the dredged area is small compared to the broad area of the west Florida shelf, it is expected that there would be a negligible impact on the ecosystem. In addition to larval recruits from the water column, the surrounding areas (that are not targeted for dredging) would supply the potential adult colonists for the area disturbed by the dredging operation. Similar to conclusions reached in previous MMS studies, the high densities and fecundity of the benthic populations in the area together with the relatively small area of impact would preclude significant long-term effects on the benthic populations.

Slow-moving and burrowing epibiota inhabiting the study area include echinoderms such as sand dollars and brittle stars and decapod taxa, and local populations of these types of benthic organisms would most likely experience a reduction in density due to sediment removal and entrainment in the suction dredge. Motile epifauna generally are migratory and are not restricted to the borrow areas.

The timing of dredging will be important because many benthic species have distinct reproductive and recruitment periods. Recovery will be primarily from larval recruitment and adult immigration. Therefore, recovery should be most rapid if dredging is completed before seasonal increases in larval abundance and adult activity. The benthic assemblages within the study area were generally dominated by small bodied, deposit-feeding species living at the sediment surface. Spionid polychaetes were numerically dominant during both surveys, and were four times as abundant during the June survey than the October survey. This pattern agrees with Diaz's (2004) conclusion that mining activities that ended before fall/winter would favor annelid recruitment. However, impacts to fish may be greater following mining in the spring/summer because recruitment of their crustacean prey would be affected (Diaz, 2004).

Based on results of other studies, it is expected that recolonization of the dredged area should begin soon after dredging activities end from larval settlement from the water column and adult and post-settlement juveniles not entrained by the dredge as well as from adjacent areas. Recolonization rates will be dependent to some extent upon the size, edge-area, and proximity of non-dredged areas within the borrow site. In addition, as previously noted, studies have indicated that although the abundance, species, and biomass of benthic infauna may approach pre-dredging levels in a relatively short time (< one yr in some cases) after dredging community composition may take much longer.

6.4 Fishes and Macroinvertebrates

Fish trawl catches were dominated by demersal soft-bottom species, most of which range widely over the Florida continental shelf (and throughout the western Atlantic Ocean) and are of little direct economic value to southwest Florida. Only five hardbottom-associated species protected under the Gulf of Mexico Fishery Management Council's reef fish management plan were collected, of which only the sand perch (*Diplectrum formosum*) was common. Further, no fishes listed as federally endangered or threatened under the Endangered Species Act (i.e., smalltooth sawfish or gulf sturgeon), those prohibited from harvest by the State of Florida, or NMFS were collected or observed. Macroinvertebrate trawl catches did include economically valuable penaeid shrimp and *Callinectes* spp. (blue) crabs, but in generally low densities. Ichthyoplankton catches were similarly dominated by taxa of little economic value (e.g., gobies, anchovies, and herring). Larvae of these families are among the most common in estuarine and shelf waters throughout Florida, and given their long pelagic stages, their distribution is likely independent of local habitat features.

Although the two sampling cruises did not fully characterize the local ichthyofauna, the sand resource areas of interest were identified by their elevated deposits of beach quality sand and thus do not offer the exposed hard-bottom necessary to support a high diversity of reef-associated fishes, as demonstrated by the catch composition. Consequently, dredging actions will likely be of little detriment to economically valuable demersal fisheries such as snappers and groupers. Further, while migratory pelagic teleost and elasmobranch fishery species (including sawfish and sturgeon) should be expected in the vicinity throughout the year, these groups are mobile and can easily avoid small scale dredging disturbance. Consequently, establishing temporal dredging windows for the local protection of fishes appears unnecessary, especially if doing so alters the timing or duration of more critical, windows established for protection of turtles or marine mammals.

6.5 Marine Mammals, Sea Turtles and Sea Birds

Literature reviews identified habitats and the likely presence of protected species of fish, invertebrates, marine mammals, sea birds, and sea turtles in the Gulf of Mexico and in the study area from 1976 to 2006. The study areas provide habitat for a subset of the biological diversity known to exist within the Gulf. Some protected species that occur in Federal waters of the Gulf were observed during field events with seasonal variation between fall and spring expressed in difference in the number of individuals and species between the two events. The presence of listed species and the seasonal variability of specific species as derived from the above sources were considered in the scheduling of the environmental window for dredging activities. Pivotal species for timing environmental windows are sea turtles, primarily Loggerheads and to a much lesser degree green turtles and Kemp’s Ridley’s. Seasonal activity of sea turtles varies according to species; yet all are present in greater numbers during nesting season from April to October. In order to minimize potential impacts to sea turtles recommendations were discussed for setting an environmental window from December to March and requiring the use of mitigation measures, such as installation of onboard trained observers, requiring turtle deflectors on the drag head, and conducting pre-dredge survey and relocation.

Sea birds and marine mammals may be present in the study areas during dredging operations. Sea birds observed in the Gulf are dominantly trans-migrants, shorebirds, wading birds, and waterfowl that may occupy the study area briefly if ever or use the dredgers, boats and boosts for temporary resting places. Various dolphin species are the most commonly observed marine mammal that may be present in the study area. Less likely to be encountered are the Sperm Whale and the North Atlantic Right Whale. Preventing potential impacts to these species is more of a matter of on-site intervention for example, installation of trained observers with the authority to reduce activities that attract sea birds to the dredge and implementation of precautionary measures to identify and avoid marine mammals.

6.6 Suggestions for Future Studies

Site-specific characterization studies conducted by contractors for the MMS in the past twenty years to assess environmental conditions for leasing offshore resources will no longer be funded as of 2006. This study and another in progress for the northeast coast of Florida are the last MMS studies for specific project areas. Lessee will be responsible for providing environmental analyses to satisfy the legal requirements for using resources in federal waters. The MMS staff requested state governments to provide a list of priority projects and/or generic research topics that could be funded within the MMS budget. A Florida Sand Management Working Group (FSMWG) was formed to facilitate discussions among stakeholders for prioritizing resources. The FSMWG met twice once in 2007 and again in 2008. Presentations were offered on the legal requirements and ongoing MMS projects. The creation of the FSMWG is a first step toward opening communication among state officials, local governments and their consultants to define future materials needs for renourishment projects. This section provides some additional recommendations for generic studies and other means of assistance for the MMS to consider.

Characterization studies completed in past years have similar basic components policy and data analysis of the potential environmental impacts from research of literature in combination with samples analyzed generally from two field events. More recently, numerical modeling to assess physical impacts of dredging to the features and to the nearshore beaches has been added. MMS might consider using funds to replicate generic studies for some components.

Policy Analysis Updates

Annually or biennially, MMS could provide a policy analysis update of regulations that must be addressed in lease agreements. MMS staff created a packet summarizing the legal requirements and an example of a lease agreement for the last FSMWG meeting. This policy analysis could be organized into table with a checklist of regulations from Section 5 of this report. The table should be updated as regulations change for permitting the use of offshore resources change or as the MMS modifies lease requirements.

Field Events for Biological Sampling

Biologists suggest rigorous before and after dredge surveys of the benthic and fish communities in regions where offshore sand sources may be dredged. The field sampling events are hampered by insufficient funding and the limited length of time to collect data that can represent the area of concern. Typically, studies conducted for three years included two planned week field events to collect benthic grab samples and fish samples. This study added observation of sea birds, sea turtles, and marine mammals.

From a fisheries perspective, rigorous surveys of fish communities prior to and following sand mining are largely lacking for the Gulf of Mexico and U.S. South Atlantic. There is also a scarcity of data on direct effects of dredging (e.g., entrainment) on coastal benthic fish faunas. The evaluation of benthic recovery and recolonization spatial and temporal process would also benefit from characterizing the community before and after dredging events.

Marine mammals, sea turtles have historical ongoing documentation that can be had from government MMS, NMFS and FWS. Seabird studies ancillary to collection of data on benthos and fish are not sufficient to identify all migratory birds and pelagic birds that may transit through an offshore region. For studies such as this, researchers must rely on existing data records. Should MMS decide seabird studies are important for offshore leases regarding wind power ornithologist specializing n seabird studies may be engaged.

Marine Operations

Marine operations are limited by the availability of capable marine vessels during seasonal events, scheduling is subject to weather conditions and fuel prices can fluctuate unexpectedly. Marine operations are expensive components of any offshore sampling plan. More in-depth characterization could take place with coordinated studies to maximize marine operation dollars and scheduling. Weather events and the expense of mob/demob for one-week sampling events in small areas could be improved by studies of longer duration and over larger areas. In addition, a cooperative agreement with sources of marine operations suitable for field sampling could be scheduled in advanced by the MMS or a MMS contractor. The Florida Institute of Oceanography (FIO) works with universities, agencies and paying clients to support marine research. The RV Suncoaster an FIO vessel was used for the 2005 field event for this study and has been used for other similar MMS studies. Scheduling the RV Suncoaster is on a first come first serve method, which results in few openings for those on a short lead-time to complete a seasonal sampling. Often the seasonal sampling windows are booked a year in advance by university faculty who receive preference. While hiring FIO vessels is ideal as fuel costs are subsidized by the state of Florida and are included in the daily rate. FIO vessels are well suited for the type of sampling that is conducted. They have the equipment and experience with researchers in offshore and coastal settings. However, in this study as in others the privately owned RV Thunderforce was hired for the 2006 event. After the hurricanes, fuel costs spiked setting higher a market price for fuel. Coordination with other investigators that are doing similar research is a possible. For this study, attempts to work with Miami University researchers collecting plankton for HAB analysis failed due to scheduling conflicts in addition to the cost. The RV Walton Smith exceeded the vessel budget by two fold.

The approach has been for the contractor to arrange marine operations on a cost plus or reimbursement method of payment within a short time to capture seasonal variation. It is recommended that the MMS engage in generic regional field studies and facilitate coordination of marine operations with a planning horizon of several years. Thus, marine operations would cost less on a daily basis, researchers could have more certainty in planning studies and the use of and storage of equipment could be negotiated.

Regional Numerical Modeling

The potential for physical impacts due to extensive excavation of borrow pits was examined in this project on a site specific basis. One site, the T1/T2 shoal system was selected due the recent limited excavation of beach quality sand and the potential for a significant volume of additional material in the future. The second study site, Siesta Shoal located offshore of Sarasota County has not yet been targeted for sand resources, but is a good example of a typical sand resource that can be found on the inner continual shelf of west Florida. The analysis of these two locations, while providing information that can be extrapolated to other similar sites, has some limitation due to variation of sedimentology, morphology and the intensity of physical processes that can be expected in an area as large as the inner shelf of west Florida. Therefore, it is recommended that modeling techniques be applied on a more regional basis over an area that includes several or more fields of shoals and other sand bodies of more limited relief.

Numerical modeling methods have now advanced to the point where regional models can be applied at temporal and spatial scales fine enough to resolve processes at the detail required to address concerns of possible impacts at shoreline. This would provide an analysis over a wider range of features and may include most inner shelf resources features likely to be developed in the near future. Numerical model runs as long two years conducted in the present study also provided some guidance about the possible physical impacts at the excavation pits. Over a period of a few years or more it is possible that complexity in local topographic relief created by dredging can evolve. Thus in addition to shoreline impacts it is recommended that both regional and local models also be designed for long-term simulations of morphologic change over a range of borrow sites.

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